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A TELEVISION RECEIVER

By C. L. RICHARDS.

Summary. Description of a television receiver designed for two scanning systems, viz., for 240 lines standard scanning and for 405 lines interlaced scanning.

Introduction

The design of a television receiver is determined to a large extent by the principle of operation of the transmitter from which radiated pictures are to be picked up, particularly by the method of scanning used and the type and form of the synchronising signals employed at the transmitter.

The television receiver described here was designed for picking up the programmes of the B.B.C. transmitter in London, as well as the transmissions from the experimental television transmitter installed at the Philips Laboratory. The London station commenced transmitting television by two different scanning methods: one with 25 pictures per second, 240 lines per picture and an aspect or picture ratio of 3 : 4, and a second with interlaced scanning with 2 × 25 pictures per second, $202^1/_2$ lines per picture and an aspect ratio of 4 : 5 [1]). The Philips transmitter can be adjusted to various scanning standards from 25 pictures with 90 lines per picture to 2 × 25 pictures with $202^1/_2$ lines per picture (interlaced scanning).

Since, in these transmitters, the method of modulating the picture and synchronising signals on the carrier wave is substantially the same, the same receiver can be employed for picking up both transmitters. Two different scanning systems are in fact provided, and each can be regulated independently, so that by changing over from one system to the other a wide range of scanning speeds can be covered. In view of the very high modulation frequencies entailed in scanning a picture resolved into 405 lines, the receiver has been designed for a maximum modulation frequency of 2.5 megacycles.

[1]) Since this article was written the 240 lines standard transmission has been discontinued in London.

Type of Signals

Vision and associated sound are transmitted by modulating each on its own carrier wave. In the case of the London transmitter, vision is for instance transmitted on a carrier wave of 45 megacycles (6.67 metres) and sound modulated on a carrier wave of 41.5 megacycles (7.23 metres). The method of modulating vision and the associated synchronising signal is shown in *fig. 1*. The or-

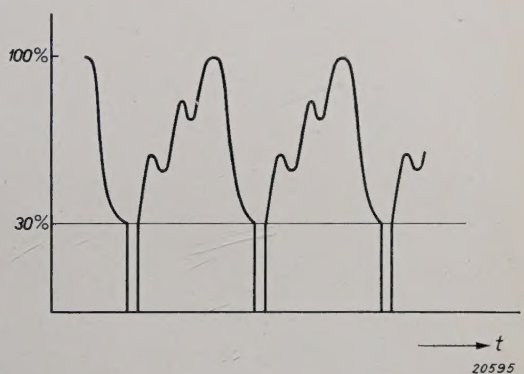

Fig. 1. Variation of amplitude of high-frequency oscillations in a wave modulated with vision signals.

dinate gives the amplitudes of the high-frequency oscillations as a percentage of the maximum amplitude. If no picture signal is received, i.e. the picture screen is perfectly dark, the modulation of the high-frequency oscillations is approximately 30 per cent. During scanning of a picture line along which the brightness fluctuates from bright to dark, the carrier wave is modulated to varying degrees between 30 and 100 per cent. At the end of each line the carrier wave is completely suppressed for a short interval (zero modulation), and this decrease in modulation from 30 per cent to zero

constitutes the line synchronising signal. Similarly at the end of each picture, a picture synchronising signal is produced, which is not shown in fig. 1.

In interlaced scanning, the synchronising signals are not produced in the same simple manner, but lack of space precludes this point being discussed in detail here.

plification must not alter the mutual positions of the oscillations with different frequencies from which the picture signal is built up, since the phase of an oscillation has a marked effect on the distribution of the bright and dark elements produced on the screen. On the other hand, television reception is simpler than sound reception inasmuch as pro-

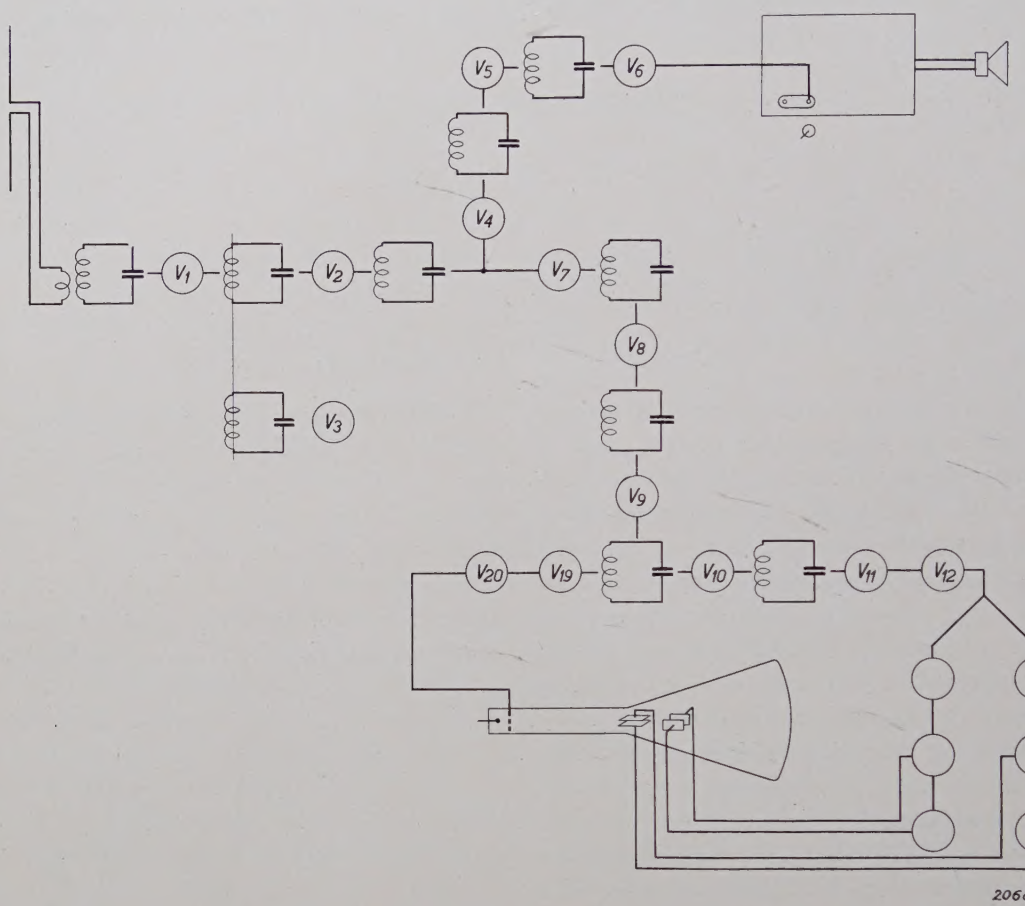

Fig. 2. Circuit diagram of a receiver set for television with associated sound.
V_1 Ultra-short wave amplifying valve for vision with sound.
V_2 Mixing valve with oscillator V_3.
V_4 to V_6 Amplification and rectification of sound signals.
V_7 to V_9 Amplification of vision and synchronising signals.
V_{19} and V_{20} Transmission of vision signals to the control electrode of the cathode-ray tube.
V_{10}, V_{11}, V_{12} Amplification of synchronising signals and transmission to the corresponding saw-tooth wave generators for deflecting the cathode ray.

Desiderata of the Television Receiver

A television receiver differs fundamentally from an ordinary radio receiver in that for the reception of television pictures a receiver must give a uniform amplification over a very wide frequency range. It is therefore not possible to use circuits with a high selectivity, so that there is a marked reduction in the amplification which can be obtained per stage. Furthermore in receiving vision — as opposed to the reception of sound — any phase displacement which may be obtained during amplification must not alter... nounced non-linear distortion is permissible. As a result, the carrier wave and one of the side bands are, for instance, quite sufficient for good reception. This offers the important advantage that the frequency band to be treated is only half as wide, so that the amplification in the individual stages is practically doubled.

Circuit Arrangements of the Receiver

In a television receiver the wave on which the picture is modulated must be picked up, amplified and rectified; the vision signal obtained in this

way must then modulate the voltage at the control electrode of a cathode-ray tube in such a way that the scanning spot on the fluorescent screen always has the same intensity as that of the corresponding point in the original picture. In addition, a scanning arrangement consisting of two saw-tooth generators is required, so that the scanning spot will cover the whole surface of the screen; a device is also needed responding to the synchronising signals picked up and thus synchronise the operation of the scanning device with that of the transmitter. Finally, the sound which is modulated on another carrier wave must also be picked up, amplified, rectified and finally passed to a loudspeaker.

In the receiver described here, a television cathode-ray tube is used giving a picture measuring 25 × 18 cm, almost white in colour and sufficiently bright for viewing in a dimly-lit room. The tube operates on an anode tension of 5000 volts. The cathode ray is deflected in both directions by electrical means through the agency of two pairs of deflecting plates; the requisite deflection voltage being approximately 1000 volts. The modulation voltage at the control electrode of the tube is approximately 30 volts.

A simplified circuit of the receiver is shown in *fig. 2*. The two carrier waves for vision and sound are picked up with the same aerial and both amplified in the same high-frequency stage by an amplifying valve V_1; the frequency characteristic of this stage must naturally be sufficiently broad for this purpose. In the top right hand corner of *fig. 3* is shown the frequency range occupied by the carrier wave and the side bands carrying the vision signals, while in the left hand corner is shown the much narrower range of the other carrier wave and the sound signals modulated on it. Curve *1* in fig. 3 shows the frequency characteristic of the high-frequency amplifying stage. The high-frequency circuits in front of and following the amplifying valve V_1 can be finally adjusted by means of small trimming condensers, thus permitting these circuits to be tuned to both the B.B.C. transmitter and the Philips transmitter.

To separate the picture and sound signals the heterodyne principle employed in radio receivers has been introduced. The two signals are passed to the mixer valve V_2 together with an auxiliary frequency generated by the oscillator V_3.

Two new carrier waves are produced in the mixer valve, each with a lower frequency than the two primary carriers. In conformity with the nomenclature employed in heterodyne radio receivers, these new waves are termed intermediate-frequency carrier waves, although their frequencies are

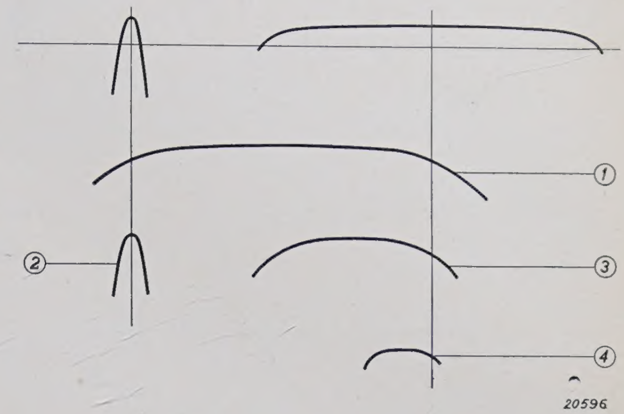

Fig. 3. Diagrammatic representation of frequency bands. Above: Radiated signals for vision and sound.
1 Characteristic of stages V_1 and V_2.
2 Characteristic of stages V_4 to V_6 for amplification of sound signals.
3 Characteristic of stages V_7 to V_9 for amplification of vision and synchronising signals.
4 Characteristic of stages V_{10} to V_{12} for amplification of synchronising signals.

situated in an entirely different band (e.g. 10 and 7·5 megacycles) than is the case in radio reception.

Vision is modulated on one intermediate-frequency carrier wave and sound on the other. The two carriers are passed together to the grids of two intermediate-frequency amplifying valves V_4 and V_7.

The anode circuit of V_4 is tuned to the sound intermedate frequency and has such a narrow frequency characteristic that the vision signals are no longer able to pass. In fig. 3 this characteristic is represented by curve *2*. In this connection it should be remembered that behind the mixer valve the signals are transmitted on an entirely different carrier; since fig. 3 is intended merely to give a general indication of the mutual positions of the frequency characteristics in the different stages, this displacement of the carriers has not been taken into consideration in this figure. The intermediate-frequency carrier modulated with vision is further amplified in V_5 in the usual way and rectified in the diode V_6; the low-frequency signal so obtained is applied to the gramophone pick-up sockets of a standard radio receiver equipped with loudspeaker and volume control.

As already indicated, the two intermediate frequency carriers are also passed to the grid of the amplifying valve V_7. The circuit following this valve, as well as the two succeeding amplifying stages with the valves V_8 and V_9, together furnish a frequency characteristic of the type shown in

curve *3* in fig. 3, so that in the anode circuit of the valve V_9 there remain only the picture and synchronising signals. Behind V_9 a separation again

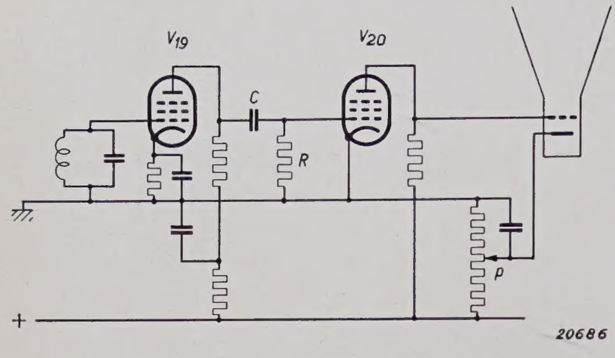

Fig. 4. Circuits of valves V_{19} and V_{20} which apply the vision signal to the control electrode of the cathode-ray tube.

takes place. Passing to the left the modulated intermediate-frequency waves reach the valve V_{19}, which functions as an anode rectifier. Following *fig. 5a;* the grid voltage adjusts itself in such a way that the peaks on the right, which in this case correspond to the base of the synchronising signal, just fall within the region in which grid current flows. For each line scanned the vision signal is of different form and in general exhibits marked fluctuations in modulation depth, as shown e.g. for two lines in fig. 5*a*. On the other hand, the synchronising signals always have the same modulation depth, so that the broken lines marked *1* and *2* will always occupy the same positions. In consequence, the values V_1 and V_2 (fig. 5*b*), of the voltage at the anode of V_{20}, corresponding to the grid voltages *1* and *2* will also always be the same irrespective of the modulation of the vision signals. The control electrode of the cathode-ray tube is connected directly to the anode of V_{20}. By applying a suitable negative tension (adjusted with the potentiometer *P*) between the control

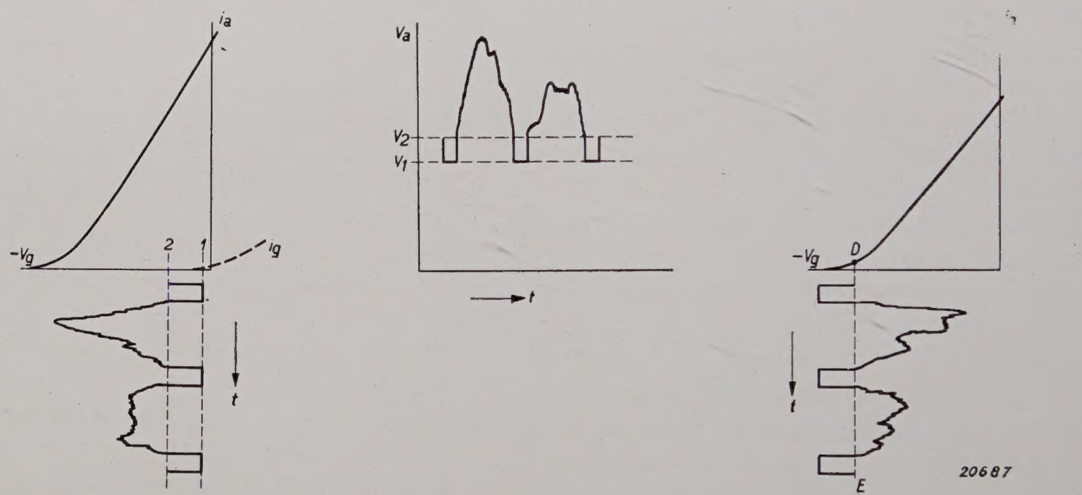

Fig 5 *a* Characteristic and applied grid voltage of valve V_{20}. *b* Anode volts of valve V_{20}. *c* Voltage at control electrode of cathode-ray tube.

rectification picture signals are obtained which can also be termed picture-frequency signals; they are amplified by V_{20} and finally passed to the control electrode of the cathode-ray tube.

Since this part of the circuit requires closer attention, it has been reproduced separately in *fig. 4.* The picture-frequency signals furnished by the anode rectifier V_{19} are passed through a condenser *C* to the grid of V_{20}; this grid is connected to the cathode through a high resistance *R*; as long as no signal is received the grid is at zero potential with respect to the cathode. If now the picture-frequency signal is applied to the grid, grid current will flow and produce a voltage drop in the resistance *R*, as a result of which the mean grid bias becomes negative. This is shown in electrode and the cathode, the picture-frequency signal can be applied to the control electrode of the cathode-ray tube in the manner shown in fig. 5*c*; it is seen that the line *DE* corresponding to the perfectly dark picture occupies such a position that current just fails to pass through the cathode-ray tube, while modulation to the right of *DE* allows a beam current to pass, which is approximately proportional to the modulation and thus increases and diminishes with the brightness of the radiated picture.

Reference will be made to some further details of the receiver circuit. Correct tuning is obtained by adjusting the oscillating circuit of the oscillator, shown next to V_3 in the circuit diagram, in such a way that the loudspeaker reproduces the sound

picked up, i.e. tuning is done on the sound and not on vision, since the circuits in the receiver have much sharper resonance curves than those of the television receiver. Automatic volume controll is provided in the sound intermediate-frequency amplifier to prevent overloading and also to minimise variations in the loudspeaker sound output, occurring as a result of a slight drift in the oscillator frequency.

It is evident from curves *1* and *3* in fig. 3 that only one of the two side bands of the carrier on which the vision signals are modulated is amplified. The suppression of the other side band does not adversely affect the quality of the picture, as has already been pointed out above.

Synchronising Signals

In discussing the receiver circuits in reference to fig. 2 it was already mentioned that an intermediate-frequency carrier on which the picture and synchronising signals are modulated is obtained in the circuit behind V_9. The carrier wave is amplified by the valve V_{10}, and the circuit following this valve has a transmission characteristic of the type shown in curve *4* in fig. 3, V_{11} is a triode with incorporated diode *(fig. 6)*. The incoming signal

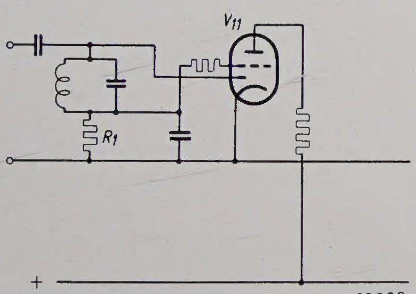

Fig. 6. Circuits of the diode-triode V_{11}. The short line represents the diode anode. In this stage the synchronising signals are separated from the vision signals.

is rectified in the diode giving a picture-frequency signal at the resistance R_1. As shown in the figure the signal is also applied at the same time to the grid of the triode. The characteristic of the triode is so chosen *(fig. 7)* that the amplitudes of the vision signals all fall within those grid voltages at which no anode current flows, while the opposite is the case for the synchronising signals. The anode current of the triode is thus of the form shown in fig. 7*b*; it is seen that the synchronising signals are almost completely separated from the vision signals proper.

The circuit shown in fig. 6 is followed by the stage V_{12}, which serves for the still more complete separation of the synchronising signals from the vision signals. Following V_{12} are filters in which the line and picture synchronising signals can be separated from each other on the basis of their

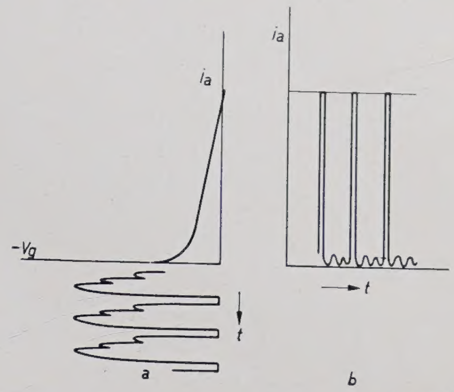

Fig. 7. *a* Characteristic and applied grid voltage of the diode-triode valve V_{11}.
b Anode current of triode section of V_{11}.

frequency difference; finally, each is applied to one of the saw-tooth wave generators serving for deflecting the cathode ray.

Saw-tooth Wave Generators

In the circuit diagram the saw-tooth wave generators are represented by two groups each composed of three circuits (not specifically indicated) on the right of the cathode-ray tube. Each of the two generators contains a condenser which is charged through a resistance and discharged by a valve (top circuit). The saw-tooth voltage of the condenser is amplified by the two amplifying valves following it, and which apply the scanning voltage to the deflection plates of the cathode-ray tube. The circuit containing the two amplifying valves is so arranged that the saw-tooth generators automatically continue in operation, even in the absence of synchronising signals. Means are also provided for improving the linearity of the saw-tooth waves. Each saw-tooth generator is actually duplicated in order to be able to employ different scanning methods, a point already indicated at the outset.

Assembly of Components

The cathode-ray tube *(f* in *fig. 8)* is mounted horizontally in a chassis *a*, on which the various amplifying stages and the saw-tooth generators are also fixed. The tube is inserted from the front, after removing a loose front panel on the cabinet. Behind this panel, those controls are also mounted which normally require a single adjustment only and need no further attention during normal operation of the apparatus.

Four control knobs serve for the adjustment of the television receiver (in the actual apparatus these are combined to a pair of twin knobs *h* and *l*),

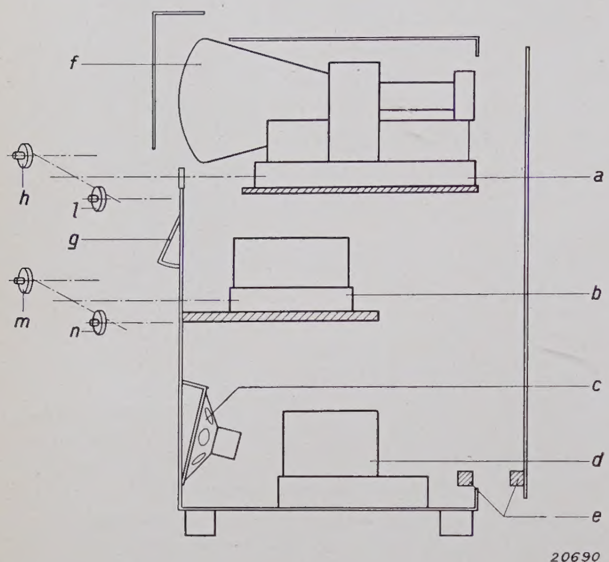

Fig. 8. Diagrammatic section through the receiving set. *a* Vision receiver. *b* Broadcast receiver. *c* Loudspeaker. *d* Anode current unit *e* Safety contact. *f* Cathode-ray tube. *g* Tuning scale of radio receiver.

Vision controls: *h* Picture adjustment. *l* Tuning and selecting of scanning method.

Radio controls: *m* Volume and band width. *n* Tuning and wave range; on and off switch; changeover for radio or television reception.

and with which the following adjustments can be made: 1. Adjustment of the amplification of the vision amplifier, permitting a variation of the amplitude of the picture-frequency signal at the control electrode of the cathode-ray tube (see fig. 5*c*) and thus increasing or reducing the brightness of the picture; 2. adjustment of the potentiometer *P* in fig. 4, permitting the line *DE* (fig. 5*c*) corresponding to a dark screen to be brought into the correct position, viz., just at the current cut-off point of the cathode-ray tube; 3: tuning of the oscillating circuit; 4: changing over from one scanning system to the other.

The chassis *b* for a broadcast receiver with the control knobs *m* and *n*, which can also be used for normal radio reception, is mounted lower in the cabinet. The television receiver is switched on in the fourth position of the wave switch, and the associated sound is then reproduced through the pick-up connections of the sound receiver.

The loudspeaker and the various anode voltage units are located is the bottom of the cabinet. All high-tension leads are provided with metallic screening throughout the set; protection against high-tension shocks is also provided, the mains voltage being cut off and the high-tension condensers discharged when the cabinet is opened.

THE REPRESENTATION OF COLOUR SENSATIONS IN A COLOUR SPACE-DIAGRAM OR COLOUR TRIANGLE

By P. J. BOUMA.

Summary. On the basis of the experimental results obtained on colour mixing, it is demonstrated how all colour sensations can be represented in a colour space-diagram and how various transformations can be applied to this space-diagram. In many cases such a space-diagram can be replaced by a suitable colour triangle. Various characteristics of these triangles, particularly the I.C.I. 1931 standard triangle (fig. 4), are discussed, and a series of formulae given for the computation of colour mixtures.

Introduction

Considering the practical importance which has been recently acquired by the problem of characterising colour sensations produced by modern sources of coloured light, it appeared to us desirable to expand our purely qualitative analysis of colour perception given in a previous paper [1]) to a more precise quantitative discussion of the method for characterising these colour sensations and to describe the experimental principles of this method.

A colour sensation is produced when a specific type of light stimulates the retina of the eye. Colour sensations produced by different means, (e.g. by mechanical agents) will not be discussed here. The nature of the colour sensation is determined by:

1) The physical composition (spectral distribution) of the incident light, and
2) The characteristics of the eye.

Construction of a Colour Space-Diagram

It is assumed that we are dealing with a "standard" and unstrained eye, which does not receive simultaneously widely-different colour stimuli. The effects of fatigue, after-images, simultaneous and successive contrast are considered to be absent. It is also assumed that the brightness level is neither so low that the Purkinje phenomenon [2]) is obtained, nor so high that a condition of glare results.

In these circumstances the well-known rule of mixture applies:

If three arbitrary relative spectral distributions (i.e. three types of light) are selected, each colour sensation can be created by suitably mixing these three "primary colours". The required result can be obtained in each case only by a specific ratio of the primary colours.

To ensure the general validity of this law we must conform with the two following new conditions:

1) The three primary colours must be selected in such a way that it is not possible to produce any one of the colours by a suitable mixture of the other two.
2) In each selection of the fundamental colours, there are always colours K present which cannot be produced in the manner indicated; in these cases it is however always possible — and actually in one way only — to select a mixture of K with one or two primary colours and to obtain an identical colour sensation by combining the two other primary colours (or by taking a specific amount of the third primary colour). The fact that a definite quantity B_1 of a certain primary colour is added to K may be expressed as follows: "We add the quantity $-B_1$ of this primary colour to the simulative mixture of the primary colours"; hence the rule of mixtures assumes general validity in that *negative* quantities of the primary colours can also be dealt with.

Since with a specific choice of the primary colours a certain colour sensation (brightness B) can be simulated in one and only one way by mixing the three primary colours with brightnesses B_1, B_2 and B_3, this colour sensation is completely characterised by the three quantities: B_1,B_2,B_3. It may be recalled that these three numerals determine merely the colour sensation and do not express the spectral composition of the light.

The totality of the colour sensations which can be produced is therefore three-dimensional, in other words if we employ a three-dimensional diagram [3]) with the co-ordinates x_1, x_2, x_3, each colour sensation can be represented by a point in

1) Philips techn. Rev. 1, 283, 1936.

2) Philips techn. Rev. 1, 102, 142, 166, 1936.

3) It is immaterial whether the systems of axes are rectangular or oblique; in figs. 1 and 2 they have been taken as oblique.

this diagram, when we take $x_1 = B_1$, $x_2 = B_2$, and $x_3 = B_3$. To each colour sensation there thus corresponds one point, and to each point no more than one colour sensation.

Characteristics of the Colour-Space-Diagram

To obtain some idea of the position of colour sensations in this space diagram, attention must be called to a few laws which with the restrictions outlined above (standard unstrained eye, brightness above the limiting value of approximately 3 candles per sq.m, etc.,) are of general validity:

1) On a proportional change in energy two "physiologically equivalent" colours remain physiologically equivalent, i.e. if two different illuminants produce the same colour sensation, this equivalence is retained when the energy of each illuminant (and hence also the brightnesses) are multiplied or reduced by the same factor (thus leaving the relative spectral distributions unaltered).
2) Physiologically equivalent colours behave similarly in any mixing process, and they can therefore be substituted for each other in any mixture [4]).
3) The brightness of a mixture is equal to the sum of the brightness values of the components.

It follows from the first law that on an alteration in the energy of an illuminant (with constant spectral composition) displacement takes place along a line through the origin in the (x_1, x_2, x_3) space diagram.

For if B (colour k) $\sim$ B_1 (colour *1*) + B_2 (colour *2*) + B_3 (colour *3*) [5]) we have according to this law:

nB (colour $k \sim n\,B_1$ (colour *1*) + $n\,B_2$ (colour *2*) + $n\,B_3$ (colour *3*).

The brightness B (colour k) thus has the co-ordinates $x_1 = B_1$, $x_2 = B_2$, $x_3 = B_3$, and the brightness $n\,B$ (colour k) the co-ordinates $x_1{}' = n\,B_1$, $x_2{}' = n\,B_2$, $x_3{}' = n\,B_3$. Displacement is thus along a straight line through the origin.

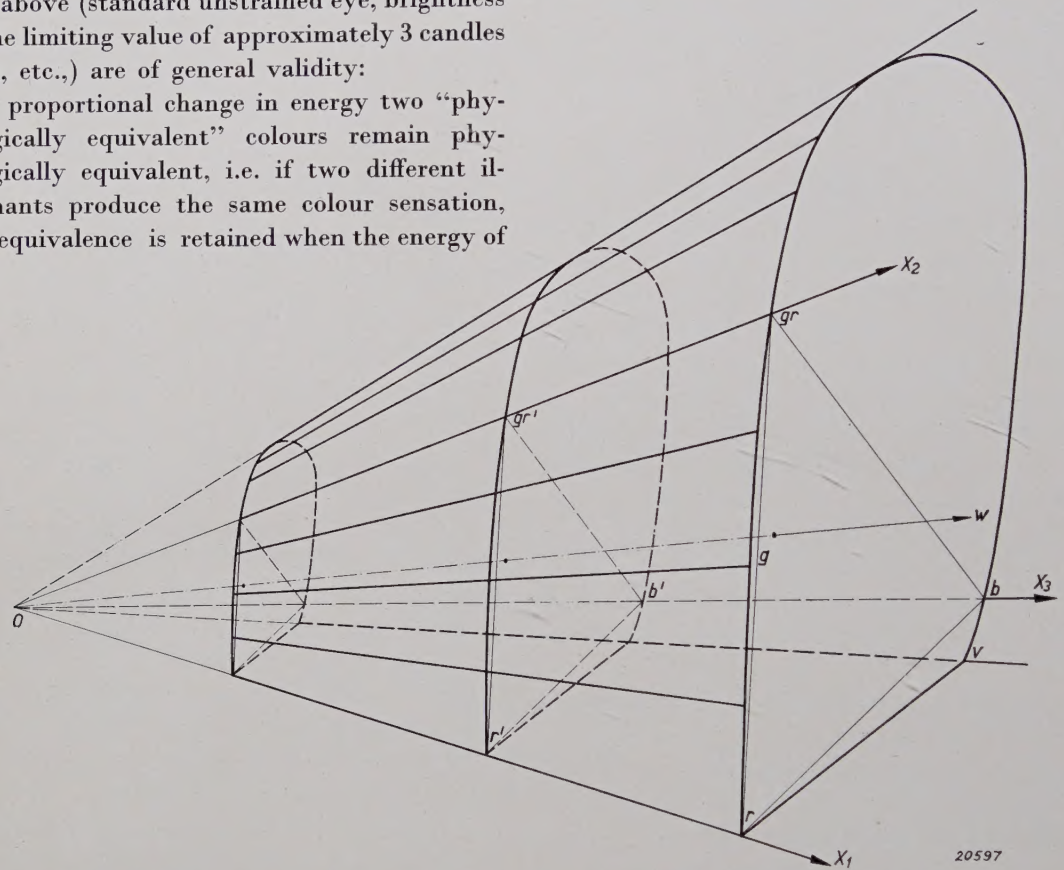

Fig. 1. Diagrammatic representation of a colour space-diagram with red, green and blue spectral colours as primary colours. The spectral colours lie on the surface of a cone, the saturated purple colours in a plane *O*-r-*v*, and all other colours within this cone. Colour triangles are obtained in the planes $x_1 + x_2 + x_3$. The line *O*-*w* represents white; the cone is truncated on the left for taking account of the Purkinje phenomenon.

In particular a line through the origin corresponds to every spectral colour. These lines lie on the surface of a cone which is shown diagrammatically in *fig. 1*, where the primary colours selected are at 4358, 5461 and 7000 Å. These are the three spectral colours which Guild and Wright employed for their calibration of the spectrum. The second is the blue mercury line and the third

[4]) It should be carefully noted that this rule does not hold in regard to the mixing of dyes.

[5]) The symbol $\sim$ is used to indicate "physiological equivalence".

the blue mercury line. The letters r, g, gr, b and v represent approximately the positions of the spectral red, yellow, green, blue and violet. r and v correspond to the ends of the spectrum. The cone is truncated to the left in accordance with the above restriction regarding the brightness level.

From the second law it follows that a mixture of colours in the space diagram can be represented by vectorial addition.

For if:

B (colour k) $\sim B_1$ (colour 1) $+ B_2$ (colour 2) $+ B_3$ (colour 3)

and:

B' (colour k') $\sim B_1'$ (colour 1) $+ B_2'$ (colour 2) $+ B_3'$ (colour 3)

then according to this law we have:

B (colour 1) $+ B'$ (colour k') $\sim (B_1 + B_1')$ (colour 1) $+ (B_2 + B_2')$ (colour 2) $+ (B_3 + B_3')$ (colour 3).

The following co-ordinates therefore apply to the colour sensations B (colour k) and B' (colour k'):

$x_1 = B_1, x_2 = B_2, x_3 = B_3$ and $x_1' = B_1', x_2', = B_2', x_3' = B_3'$

and to the mixture of these two colours:

$x_1'' = B_1 + B_1', x'' = B_2 + B_2', x_3'' = B_3 + B_3'$.

The vector (x_1'', x_2'', x_3'') is thus actually obtained by adding the vectors (x_1, x_2, x_3) and (x_1', x_2', x_3').

We also see why the primary colours may not be selected in such a way that one of them can be produced by a mixture of the other two: Such a combination of three primary colours would be shown in fig. 1 by three coplanar vectors, and with these primary colours only the colour sensations laying in this plane could be obtained. It follows furthermore from the rule of mixtures deduced above that:

1) The plane O-v-r contains the mixtures of spectral red and spectral violet (saturated purples).
2) All mixtures of spectral colours (i.e. all colour sensations) lie within the surface of the cone formed by the spectral colours and the plane O-v-r. In other words: Each point within this conical surface represents a specific colour sensation; a point outside this surface represents no colour sensation at all and has therefore only a geometrical significance. The line O-w represents white light.

From the third law we get the brightness equation:

$$B = B_1 + B_2 + B_3 \quad \text{or} \quad B = x_1 + x_2 + x_3. \quad (1)$$

In fig. 1, r-gr-b and r'-gr'-b' are planes which cut off equal lengths from the three axes; their equation is therefore $x_1 + x_2 + x_3 =$ constant, and these planes are thus planes of constant brightness.

Transformations of the Colour Space-Diagram

Having represented the various colours in this way we can pass in different ways from this system to other systems, in which a colour is determined by three other numerals, i.e. we can transform the colour space-diagram obtained in various ways.

The most important transformation is the homogeneous linear transformation, which consists in substituting the co-ordinates (x_1', x_2', x_3') for the co-ordinates (x_1, x_2, x_3), the relationships between the two sets of co-ordinates being as follows:

$$\left.\begin{aligned} x_1 &= a_1 x_1' + a_2 x_2' + a_3 x_3' \\ x_2 &= b_1 x_1' + b_2 x_2' + b_3 x_3' \\ x_3 &= c_1 x_1' + c_2 x_2' + c_3 x_3' \end{aligned}\right\} \quad . \; . \; . \quad (2)$$

This substitution corresponds to a geometrical rotation of the axes with simultaneous and different contraction or elongation in the directions of the three axes. In many cases this can be interpreted physically by a different choice of primary colours coupled with a choice of different brightness units for the three different primary colours. But this interpretation is only applicable if the new axes lie within the cone in fig. 1. If they are outside it (and transformations of this type are frequently employed in practice) transformation (2) loses its simple physical meaning. It is advisable therefore to regard this transformation always as a pure mathematical artifice [6]). The purpose of these transformations is purely of a practical nature, for by a suitable choice of the coefficients in (2) different purposes can be served, e.g.:

1) The white line O-w can be brought into a specific position with respect to the axes, e.g. so that it can be represented by the equation $x' = x_2' = x_3'$;
2) The brightness equation which after transformation is:

   $$B = (a_1 + b_1 + c_1)\, x_1' + (a_2 + b_2 + c_2)\, x_2' + (a_3 + b_3 + c_3)\, x_3'\,;$$

   can be given a specific form, e.g.

   $$B = x_2'\,;$$

3) That all colour sensations shall have positive co-ordinates exclusively; this cannot be done if the three axes are all within the cone of fig. 1 or lie along its surface. These axes can therefore no longer be regarded as representing colours.

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[6]) We prefer this interpretation to the introduction of the rather problematic and obscure concept of "imaginary primary colours". A line outside the cone does not represent an imaginary colour but it represents no colour at all.

Fig. 2 shows an example of a colour space-diagram which has been obtained by a transformation of this type and which has the three above-mentioned characteristics. The planes $x_1' + x_2' + x_3' =$ constant shown are now no longer planes of constant brightness, such planes then being all parallel to the plane O-x_1'-x_3' [7]).

Construction of Colour Triangles

Since all colours which lie in a straight line through the origin appear to be of practically the same character to the eye and only differ in brightness, it is frequently desirable to replace such a line by a point. This can be done by the following transformation:

$$\left.\begin{aligned} t_1 &= \frac{x_1}{x_1 + x_2 + x_3} \\ t_2 &= \frac{x_2}{x_1 + x_2 + x_3} \\ t_3 &= \frac{x_3}{x_1 + x_2 + x_3} \end{aligned}\right\} \quad \ldots \ldots \quad (3)$$

7) The truncation of the cone made necessary by the Purkinje phenomenon has not been shown in this figure. It would also be parallel to the plane O-x_1'-x_3'.

All points on a straight line through O have the same co-ordinates (t_1, t_2, t_3), and the equation $t_1 + t_2 + t_3 = 1$ is always satisfied. We can therefore say that if we are only interested in the character of a colour sensation and not in its brightness, it is sufficient to know the ratio of x_1, x_2 and x_3, i.e. the co-ordinates (t_1, t_2, t_3). The co-ordinates determined by equation (3) can be represented in different ways:

1) In an equilateral triangle. If we draw an equilateral triangle with height 1, the well known property, that the sum of the distances of any point from the three sides of the triangle is always equal to unity, allows us to represent the colour (t_1, t_2, t_3) by a point with distances t_1, t_2 and t_3 from the three sides. Geometrically we can visualise such a triangle being obtained by choosing the trihedral angle O-x_1-x_2-x_3 in the corresponding colour space-diagram equilateral and projecting the space from the centre on to a plane $x_1 + x_2 + x_3 =$ constant (which is generally not a plane of constant brightness).

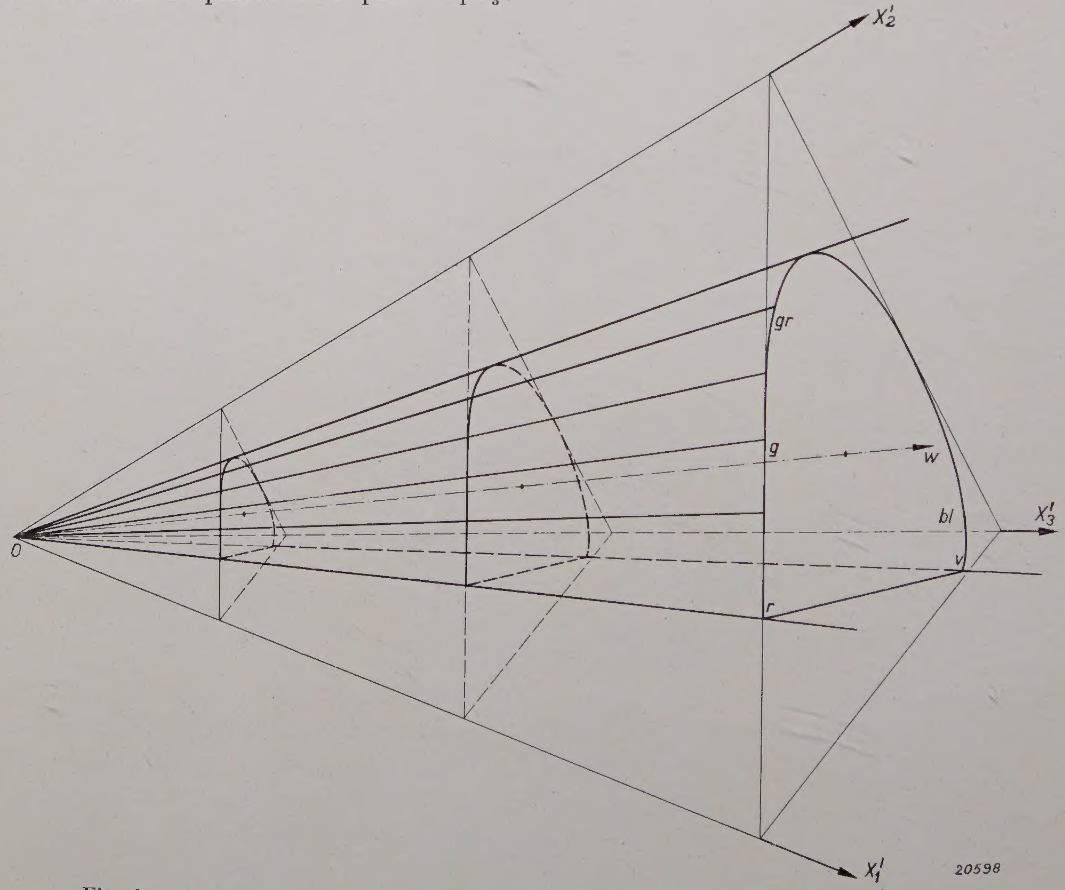

Fig. 2. Diagrammatic representation of a colour space-diagram obtained from fig. 1 by linear transformation. The axes of co-ordinates lie outside the colour cone. O-w (white) has equal distances to the three axes. Contrary to fig. 1 all colours have three positive co-ordinates.

Examples of this geometrical construction are shown in figs. 1 and 2.

2) In an isosceles right-angled triangle (the advantage being that it is easier to construct). Since $t_1 + t_2 + t_3 = 1$ it is sufficient to give two of the co-ordinates, for instance t_2 and t_3. We can therefore also plot the points in a rectangular system of co-ordinates, with t_3 and t_2 as abscissa and ordinate. It is readily seen that then $t_1 = \sqrt{2}$ times the distance of the point from the line $t_2 + t_3 = 1$ (the hypotenuse of the triangle).

The following illustrations give examples of colour triangles (drawn from the second method) with spectral colours and the white point W both inserted, and which have been derived from different space-diagrams:

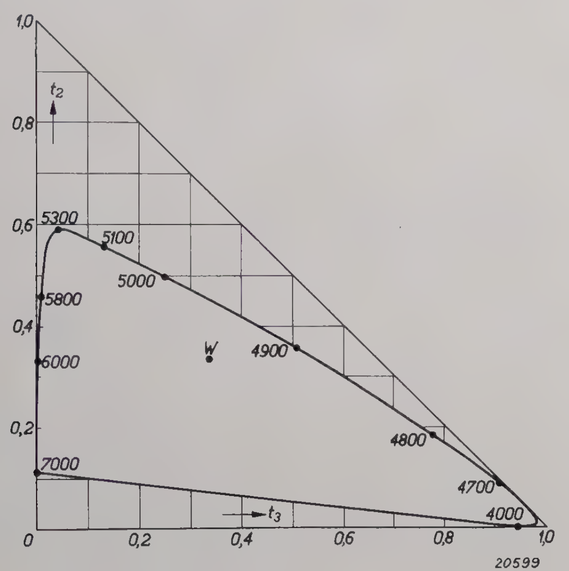

Fig. 3*a*. A colour triangle based on the early measurements of König. For white we have here $t_1 = t_2 = t_3$. The brightness equation for the corresponding space diagram is:

$$B = 0.568\ x_1 + 0.426\ x_2 + 0.006\ x_3$$

The axes are outside the spectral cone and are chosen in those directions in which we can move through space without certain types of dichromates perceiving any change. If we assume that the three dimensional nature of the totality of colour sensations is due to the existence of three photo-sensitive systems in the eye (red, green and blue systems), and that in those suffering from colour blindness one of the systems is lacking and that a white sensation is obtained by an equivalent stimulus of each of these three systems, the triangle 3*a* will represent approximately to what extent these systems are stimulated by specific types of light.

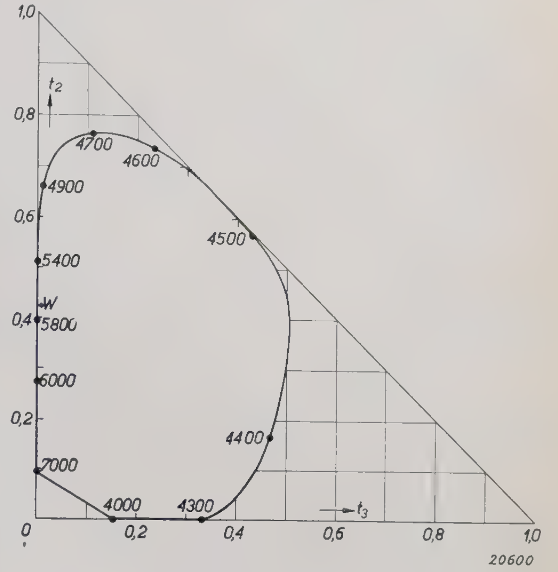

Fig. 3b. A colour triangle based on the same measurements as fig. 3a, and for whose space-diagram the brightness equation $B = x_1' + x_2' + x_3'$ applies. By the transformation $x_1' = 0.568\ x_1$, $x_2' = 0.426\ x_2$, $x_3' = 0.006\ x_3$ this space diagram becomes transformed to the previous diagram. The advantages of the simpler brightness equation and the simpler rule of mixing resulting therefrom (see below) are discounted by the serious disadvantage that the white point W is now situated very close to the spectral curve and an appreciable part of the colours is hence concentrated in a small space. For this reason space diagrams with $B = x_1' + x_2' + x_3'$ are never used in practice.

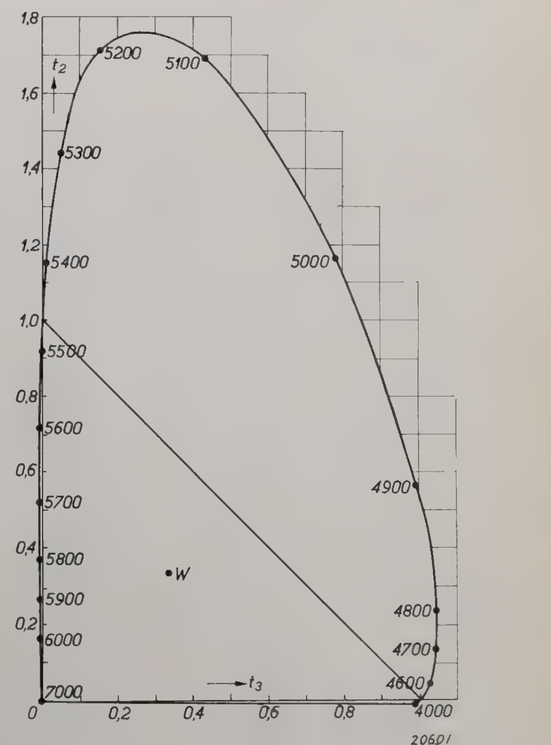

Fig. 3c. A colour triangle reproducing the recent measurements of Guild and Wright. The primary colours chosen here are the spectral colours 4358 A,

5461 Å and 7000 Å; the brightness equation for the space-diagram is $B = x_1 + 4.39\ x_2 + 0.048\ x_3$. The white (the standard N.P.L. white fixed by the National Physical Laboratiory which very closely resembles sunlight) is located at the centroid of the triangle. As is always the case where the axes of the space diagram actually represent colours, some colours occur with negative co-ordinates (thus for $\lambda = 5000$ Å, t_1 is negative).

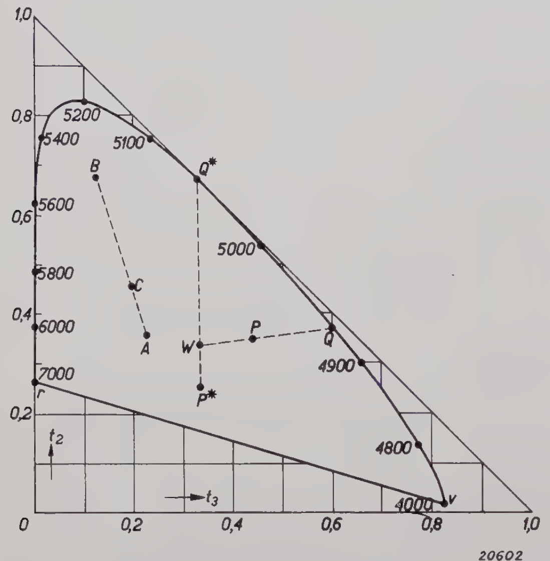

Fig. 3*d*. Another colour triangle also based on the measurements of Guild and Wright. This triangle was recommended in 1931 by the International Commission on Illumination (I. C. I.) and is now employed internationally. The white (here the equal energy spectrum, i.e. the spectrum which has the same energy $E\,d\,\lambda$ in all wave length regions $\lambda \rightarrow \lambda + d\,\lambda$) is located at the centroid; two of the sides touch the spectral curve [8]); the brightness equation in the corresponding space-diagram is: $B = x_2$. In a physical sense this equation has a some what surprising character as it does not contain the co-ordinates x_1 and x_2; but it must be remembered that this system has been evolved by a purely formal mathematical transformation from a system in which the physical interpretation of all magnitudes and formulae was directly apparent. The corresponding space diagram is shown in fig. 2.

Characteristics, Concepts and Formulae of Colour Triangles

Rules of Mixtures. From the space-diagram rule of mixing (vectorial addition) it follows immediately, in conjunction with the geometrical method of construction of the colour triangle, that in the triangle all mixtures of two colours lie on the line joining the colours [9]).

The position of the mixture on the join depends on the brightness ratio of the components. If A (t_1, t_2, t_3) and B $(t_1', t_2'\ t_3')$ represent the colours in the triangle which are mixed with brightness B and B' (fig. 3*d*) and if the brightness equation for the corresponding space-diagram is $B = ax_1 + bx_2 + cx_3$, then it can be shown mathematically that the position of the point C representing this mixture is given by the expression:

$$\frac{A\,C}{C\,B} = \frac{B'}{B}\,\frac{a\,t_1 + b\,t_2 + c\,t_3}{a\,t_1' + b\,t_2' + c\,t_3'}\,.$$

For colour triangles derived from space diagrams with $B = x_1 + x_2 + x_3$, this expression becomes:

$$\frac{A\,C}{C\,B} = \frac{B'}{B}\,.$$

The mixture of two colours having equal brightnesses is in this case always located at the midpoint of the line joining the colours. For the colour triangle in fig. 3*d* we have:

$$\frac{A\,C}{C\,B} = \frac{B'}{B}\,\frac{t_2}{t_2'} \quad \ldots\ldots \quad (4)$$

Dominant Wave-Length and Colorimetric Purity. It is seen from fig. 3*d* that a colour P (t_1'', t_2'', t_3'') brightness B'' can be obtained by mixing white light with brightness B' with a brightness B' of a specific spectral colour Q (t_1', t_2', t_3'). The wave length of Q is termed the dominant wave length, and the ratio $E = B'/B''$ the colorimetric purity of the colour P.

The colours P^* which lie in the triangle r-W-v (fig. 3*d*) cannot be formed from white light and a spectral colour; yet the colour P^* (t_1'', t_2'', t_3'') (with brightness B'') can be mixed with spectral colour Q^* (t_1, t_2, t_3) (with a brightness B') the result being white light (t_1, t_2, t_3) (with brightness B). In this case the wave-length of Q^* is termed the dominant wave length, and the ratio $\sigma = -\ B'/B''$ the colorimetric purity of the colour P^*: points in the r-W-v triangle (purples) therefore have a negative colorimetric purity.

[8]) By very careful interpolation it is found that this is not quite correct for the hypotenuse in fig. 3*d*; the difference is however extremely small.

[9]) This rule was introduced in the previous article as a convention. It is shown here that this convention was quite justified.

For all points in the colour triangle the equation applies:

$$\sigma = \frac{WP}{WQ} \cdot \frac{a\,t' \;\; + b\,t_2' + c\,t_3'}{a\,t_1'' + b\,t_2'' + c\,t_3''} =$$

$$= \frac{t_i - t_i''}{t_i - t_i'} \cdot \frac{a\,t_1' + b\,t_2' + c\,t_3'}{a\,t_1'' + b\,t_2'' + c\,t_3''},$$

where *1*, *2* or *3* can be substituted for i as required, while WP/WQ must be taken negative, when W lies between P and Q, and positive when P lies between Q and W.

For colour triangles whose space diagram is given by $B = x_1 + x_2 + x_3$, the colorimetric purity is given by:

$$\sigma = \frac{WP}{WQ} = \frac{t_i - t_i''}{t_i - t_i'}\,.$$

For the triangle in fig. 3*d* we thus have:

$$\sigma = \frac{WP}{WQ} \cdot \frac{t_2'}{t_2''} = \frac{t_i - t_i''}{t_i - t_i'}\,\frac{t_2'}{t_2''} \quad . \; . \quad (5)$$

This triangle has been reproduced again in *fig. 4* with the curves of constant colorimetric purity inserted. Since equation (5) also contains the factoı t_2'/t_2'', the scale of colorimetric purity along a straight line through W is generally not uniform (especially marked deviations in the blue).

Determination of the point in the colour triangle corresponding to a specific spectral distribution $E(\lambda)$.

Consider the various spectral colours are taken in turn each with the same energy. These different colour sensations will give points in the space diagram which form a curve on the spectral conical surface:

$$x_1 = x_1(\lambda),\; x_2 = x_2(\lambda),\; x_3 = x_3(\lambda).$$

For the space diagram from which fig. 4 was derived the co-ordinates for this curve are given in *Table I.*

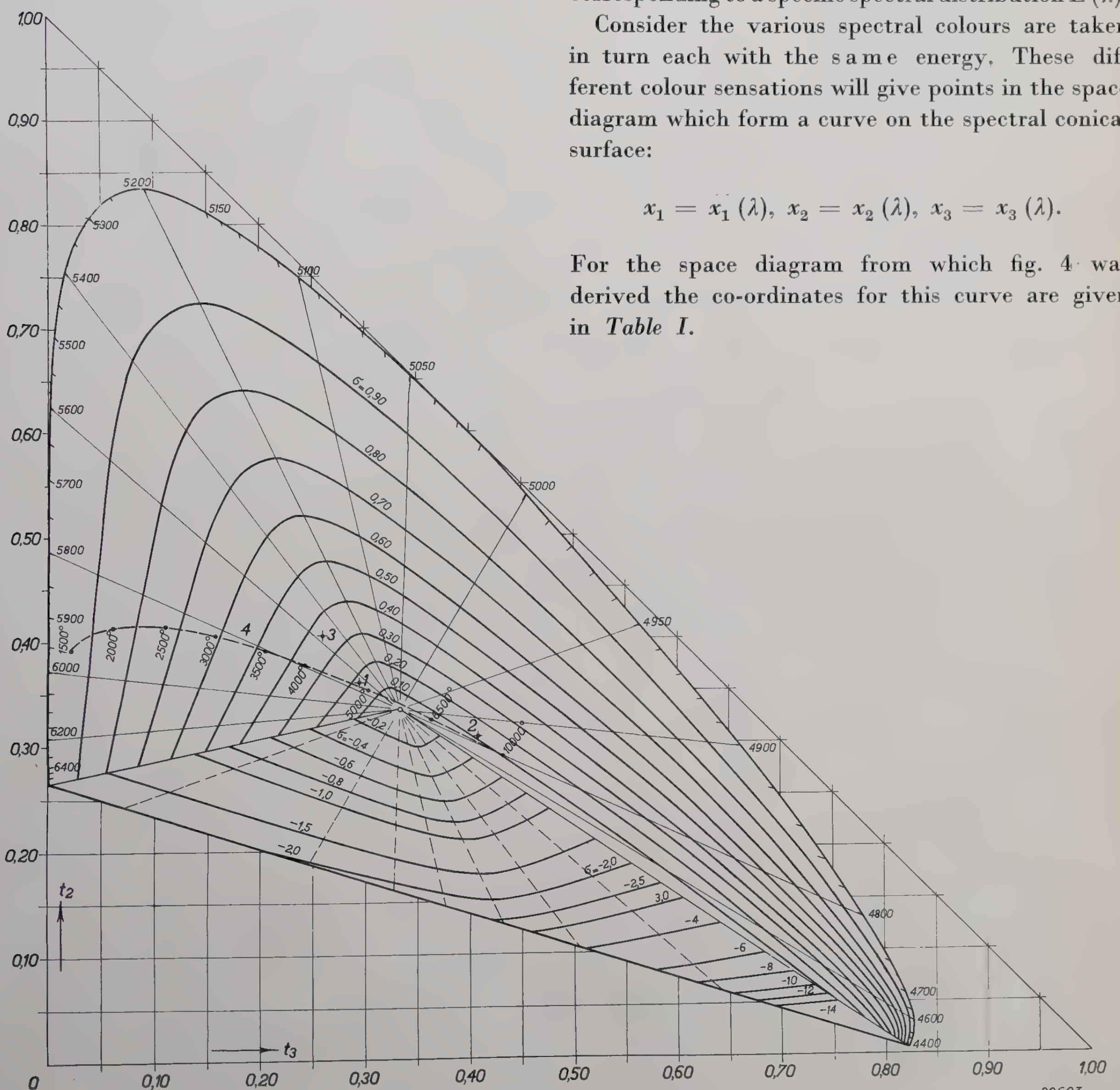

Fig. 4. The colour triangle specified by the I.C.I. (see also fig. 3*d*) with lines of constant colorimetric purity and a series of special points: 1) Daylight (sun and sky); 2) Blue sky; 3) Mercury light; 4) Black-body radiation.

Table I. Colour co-ordinates based on the I.C.I. System.

λ	$\bar{x}_1(\lambda)$	$\bar{x}_2(\lambda)$	$\bar{x}_3(\lambda)$	λ	$\bar{x}_1(\lambda)$	$\bar{x}_2(\lambda)$	$\bar{x}_3(\lambda)$
3800	0.0014	0.0000	0.0065	5800	0.9163	0.8700	0.0017
3900	0.0042	0.0001	0.0201	5900	1.0263	0.7570	0.0011
4000	0.0143	0.0004	0.0679	6000	1.0622	0.6310	0.0008
4100	0.0435	0.0012	0.2074	6100	1.0026	0.5030	0.0003
4200	0.1344	0.0040	0.6456	6200	0.8544	0.3810	0.0002
4300	0.2839	0.0116	1.3856	6300	0.6424	0.2650	0.0000
4400	0.3483	0.0230	1.7471	6400	0.4479	0.1750	0
4500	0.3362	0.0380	1.7721	6500	0.2835	0.1070	0
4600	0.2908	0.0600	1.6692	6600	0.1649	0.0610	0
4700	0.1954	0.0910	1.2876	6700	0.0874	0.0320	0
4800	0.0956	0.1390	0.8130	6800	0.0468	0.0170	0
4900	0.0320	0.2080	0.4652	6900	0.0227	0.0082	0
5000	0.0049	0.3230	0.2720	7000	0.0114	0.0041	0
5100	0.0093	0.5030	0.1582	7100	0.0058	0.0021	0
5200	0.0633	0.7100	0.0782	7200	0.0029	0.0010	0
5300	0.1655	0.8620	0.0422	7300	0.0014	0.0005	0
5400	0.2904	0.9540	0.0203	7400	0.0007	0.0003	0
5500	0.4334	0.9950	0.0087	7500	0.0003	0.0001	0
5600	0.5945	0.9950	0.0039	7600	0.0002	0.0001	0
5700	0.7621	0.9520	0.0021	7700	0.0001	0.0000	0

The following formula is employed to determine the point in the triangle corresponding to a given spectral distribution:

$$t_1 : t_2 : t_3 = \int E(\lambda)x_1(\lambda)d\lambda : \int E(\lambda)x_2(\lambda)d\lambda : \int E(\lambda)x_3(\lambda)d\lambda, \quad (6)$$

or for a line spectrum, the expression:

$$t_1 : t_2 : t_3 = \Sigma E(\lambda)\, x_1(\lambda) : \Sigma E(\lambda)\, x_2(\lambda) : \Sigma E(\lambda)\, x_3(\lambda). \quad (7)$$

In fig. 4 a number of these calculated spectral distributions have been inserted.

1) Daylight (mean result of measurements of Miss Eymers) consisting of a combination of direct sunlight and reflected sky radiation. Dominant wave length 5600 to 5770 Å; colorimetric purity 0.14 to 0.22.
2) Light of blue sky (Eymers): Dominant wave length 4835 to 4855 Å; colorimetric purity 0.09 to 0.13.
3) Mercury light (1 atmos. pressure).
4) The dash line represents black-body radiation at various temperatures. Close to $T = 2800$ °K is the colour of glowlamp light.

Fig. 4 can be used for the graphical determination of the dominating wave length (λ) and the colorimetric purity (see equation (5)) from the co-ordinates (t_1, t_2, t_3). As examples:

$t_1 = 0.1$, $t_2 = 0.5$, $t_3 = 0.4$ gives $\lambda = 5021$ Å, $\sigma = 0.81$ (fairly saturated blue-green)

$t_1 = 0.4$, $t_2 = 0.2$, $t_3 = 0.4$ gives $\lambda = 5215$ Å, $\sigma = -1.12$ (a mixture of purple and white with green complementary colour).

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In addition to the construction of the colour space-diagram this paper also deals with the "Physiological interval" between two points in the space-diagram.

Bouma and Heller, Proc. Kon. Ak. Wet. A'dam. **38**, 34. 148, 258, 1935.
The analysis is expanded to the brightness levels where the Purkinje phenomenon takes place.

[10]) It should be noted that the formulae on pp. 168 and 169 of this article are not correct.

OCTAVES AND DECIBELS

By R. VERMEULEN.

Summary. With the aid of practical data, the relationships are discussed between the acoustic magnitudes: Pitch interval and loudness, and the corresponding physical magnitudes: frequency and sound intensity. The object of this article is to emphasise that the logarithmic units, octaves and decibels, should be given preference in acoustics for denoting physical magnitudes.

Why is a preference shown in acoustics and associated subjects for logarithmic scales and are even new units introduced to permit the employment of such scales? The use of logarithmic scales in acoustics is justified from a consideration of the characteristics of the human ear, apart from many other advantages offered in both this and other subjects. Reasons for this are that to a marked extent acoustic measurements, and particularly technical sound measurements, represent attempts to find a substitute for direct judgement by means of the ear. An instructive example of this is offered in the determination of the characteristics of a loudspeaker, in which not only must the reproduced music and speech be analysed critically but *inter alia* the loudness also determined, i.e. the sound output of the loudspeaker at different pitches for an equivalent electrical power input. Yet neither the loudness nor the pitch is a physical magnitude; these are physiological and even to some extent psychological factors, which cannot be evaluated by direct measurement, since they are purely subjective. To arrive at a numerical value it is therefore necessary to make do with an objective measurement of specific physical factors, and in the case under discussion, for instance, the sound output measured as a function of the frequency. To do this it is very desirable to select such units for expressing the results arrived at that the numerical values are to some extent proportional to the corresponding physiological sensations. The same applies to electrical magnitudes when these are used for sound transmission, as for instance in telephony.

Pitch and Frequency

It is well-known that the pitch is related to the frequency of the fundamental tone [1]). That this relationship, is, however not a linear function will be evident from the following considerations. In music, where without any close insight into the physics of sound the pitch has always been denoted in musical scores by notes, the concept "musical or pitch interval" has been introduced to represent a specific difference in pitch. The most important pitch interval is the o c t a v e: Two tones which are at an interval of an octave have such a marked natural similarity that musicians have not considered it necessary to introduce different names for them, but have merely distinguished them by means of indices. In addition to the octave, there are pitch intervals, such as the fifth, fourth and several others, which are similarly perfectly natural and self-evident, not only because two tones which differ from each other by such a pitch interval harmonise with each other, but also, and this is the more important for what follows, because such pitch intervals occur at all pitches with equivalent differences.

Musicians therefore indicate the pitch in musical notation in such a way that a pitch interval nearly always corresponds to the same difference in pitch [2]), independent of the absolute pitch value. The keyboard of the pianoforte is also based on the principle that equal pitch intervals are reproduced at uniform intervals throughout the whole compass of the instrument.

A pitch interval regarded from the physical aspect is, however, not representative of a specific d i f f e r e n c e, but of a specific r a t i o of frequencies, an octave corresponding to a doubling of the frequency, and the fifth to a ratio of 2 : 3, etc. (see *Table I*). The l o g a r i t h m of the frequency shares in common with the pitch the property that on an alteration of the tone by the same pitch interval it always increases by the same amount, irrespective of the absolute frequency values:

$$\log \frac{f_1}{f_2} = \log f_1 - \log f_2.$$

[1]) That this relationship is not strictly absolute, but is determined somewhat by the intensity and timbre, is left unconsidered here.

[2]) These intervals are not absolutely equal since the pitch interval between two successive tones in musical notation is usually equal to a whole tone but sometimes also equal to a semitone.

Hence in the light of our introductory remarks the logarithm is a suitable measure for the pitch.

Octaves

Owing to the fundamental importance of the octave to hearing it appears desirable to select not 10 the Briggsian base, but the number 2 as the base of logarithms. In this way we get for the magnitude I of a pitch interval with the octave as unit:

$$I = {}^{2}log\frac{f_1}{f_2} = 3.320\ {}^{10}log\frac{f_1}{f_2}.$$

The octave can be subdivided in various ways. The most common subdivision has been developed from the desire to arrive at a scale enabling the natural pitch intervals to be obtained with the minimum number of keys per octave in instruments with a fixed keyboard, such as the organ and pianoforte. The principal natural pitch intervals are shown on a logarithmic scale in *fig. 1* with a

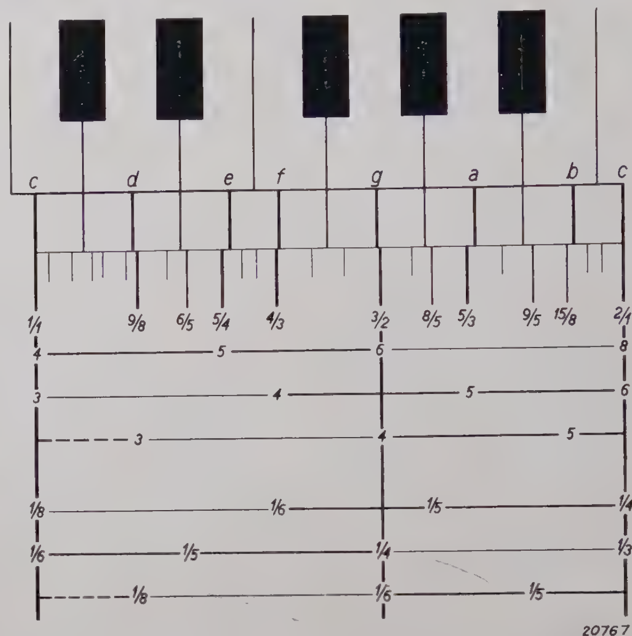

Fig. 1. Pitch intervals and scales. Below the keyboard of the pianoforte, the frequency ratios of the tones on the tempered scale are given logarithmically, and below these again the ratios for tones with natural pitch intervals. The musical notation of the notes is indicated by letters and the frequency ratios of the natural tones based on the fundamental tone C by vulgar fractions. The tones of the major scale are indicated by thick lines, and may be regarded as evolved by a threefold application of the major chord whose tones have a frequency ratio of 4 : 5 : 6, i.e. a major third and a fifth. The figure shows how with this chord the tones of the scale are obtained. It follows from the figure that this scale can be represented to a close approximation by those tones on the tempered scale which correspond to the white keys on the pianoforte.
The pitch intervals, which are shown by slightly thinner lines and which may partly be approximately represented by the black keys, have been arrived at by corresponding application of the minor chord. This minor chord may be regarded as a harmonic of the major chord; it is made up from the frequency ratio (1/4 : 1/5 : 1/6). The tempered scale gives an additional two tones between C and D and between F and G, to which no simple pitch intervals of C correspond. It will be seen, however, that these are required for arriving at the natural pitch intervals by taking one of the other tones of the scale as roots.

fundamental tone denoted by "C" as the tone of origin. If the same pitch intervals were furthermore based on one of the tones obtained in this way, new tones would be continually produced, some of which are shown in the figure by thin lines; it is thus seen that a finite number of scale divisions does not suffice. Nevertheless it is found that the most important pitch intervals can be obtained to a very close approximation by subdividing the octave into twelve equal parts, which are also shown in fig. 1 and by which additional new tones are obtained between C and D and between G

Table I.

1	2	3	4	5	6	7
Pitch interval	Tone	Frequency ratio			Milli-octaves	
		Natural scale		Tempered scale	Natural scale	Tempered scale
Unison	C	1	1.000	1.000	0	0
Comma		81/80	1.013	1.000	17.92	0
Semitone	C♯	25/24	1.042	1.059	58.89	83.33
Limma		16/15	1.067	1.059	93.11	83.33
Minor second	D♭	27/25	1.080	1.059	111.0	83.33
		10/9	1.111	1.122	152.0	166.6
Major second	D	9/8	1.125	1.122	169.9	166.6
Augmented second	D♯	75/64	1.172	1.189	228.8	250.0
Minor third	E♭	6/5	1.200	1.189	263.0	250.0
Major third	E	5/4	1.250	1.260	321.9	333.3
Diminished fourth	F♭	32/25	1.280	1.260	356.1	333.3
Augmented third	E♯	125/96	1.302	1.335	380.7	416.5
Perfect fourth	F	4/3	1.333	1.335	414.8	416.5
Augmented fourth	F♯	25/18	1.389	1.414	473.9	500.0
Diminished fifth	G♭	36/25	1.440	1.414	526.1	500.0
Perfect fifth	G	3/2	1.500	1.498	585.0	583.3
Augmented fifth	G♯	25/16	1.562	1.587	644.0	666.6
Minor sixth	A♭	8/5	1.600	1.587	678.1	666.6
Major sixth	A	5/3	1.667	1.682	737.0	750.0
Augmented sixth	A♯	125/72	1.736	1.782	795.8	833.3
Minor seventh	B♭	9/5	1.800	1.782	848.0	833.3
Major seventh	B	15/8	1.875	1.883	906.9	916.6
Diminished octave	C♭	48/25	1.920	1.883	941.1	916.6
Augmented seventh	B♯	125/64	1.953	2.000	965.7	1000.0
Octave	C′	2	2.000	2.000	1000.0	1000.0

In addition to the musical notation (2), the above table gives for the various pitch intervals, which are also indicated in fig. 1, the following data: (3) the numerical ratio determining the pitch interval and which for the less simple pitch intervals is always a simple ratio, e.g. $125/64 = (5/4)^3$ (i.e. the pitch interval is composed of three successive thirds). The next column (4) gives this fraction in decimals, while (5) gives the tempered scale approximating to the natural pitch interval. In the last two colums both the natural (6) and the tempered (7) scales are given in milli-octaves.

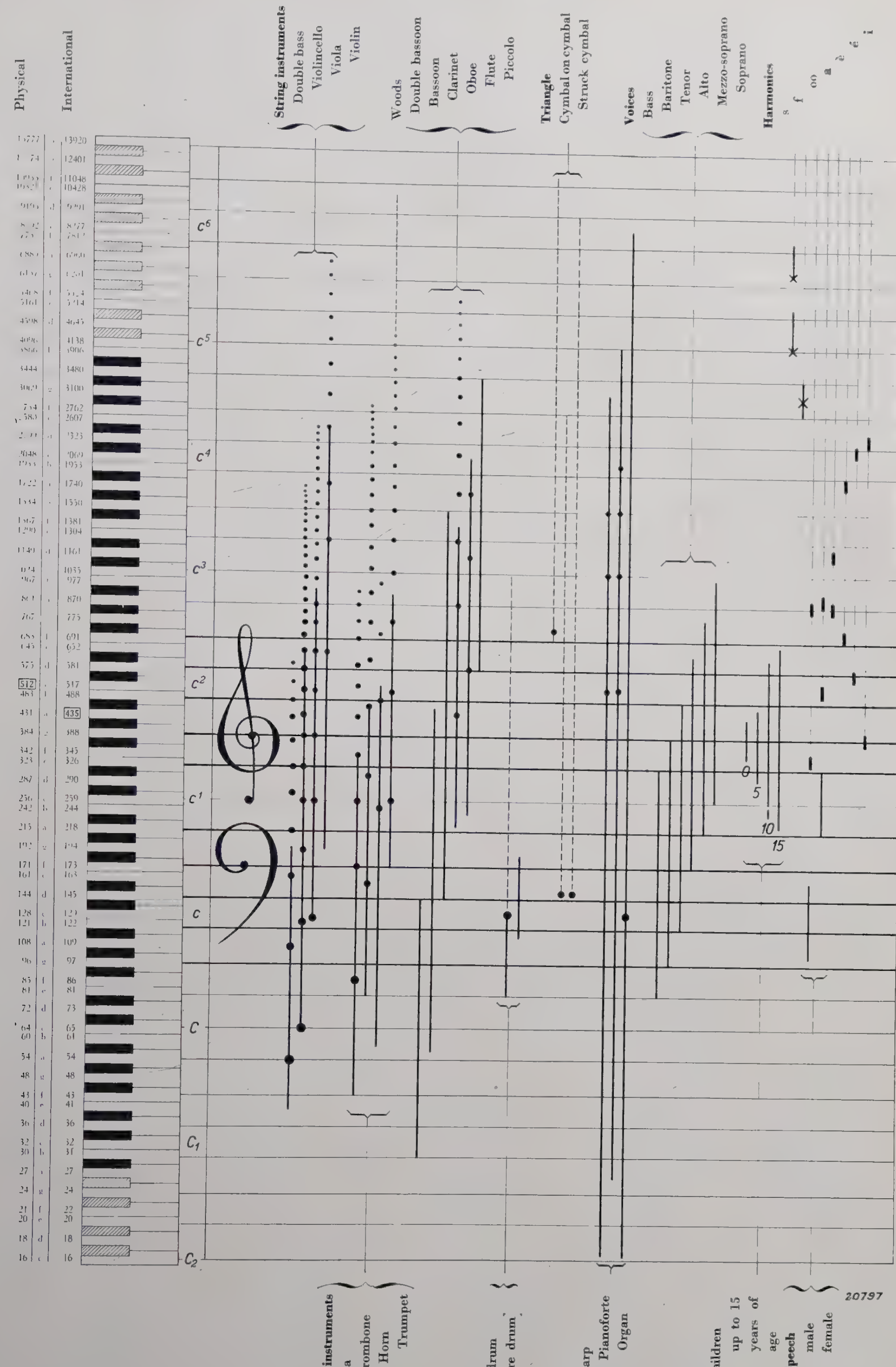

Fig. 2. Compass of musical instruments and voices. The frequency range of the fundamental tone for various musical instruments and voices is shown by a continuous line. For a number of tones (heavy dot) the corresponding harmonics have been included as small dots or a broken line. For speech the characteristic overtones (socalled harmonics) have been included in the figure.

and A. Such uniform subdivision, termed a scale of just temperament, has the advantage over scales based on natural pitch intervals that deviations in the pitch intervals on a keyboard from the natural intervals are always of the same magnitude, irrespective of the fundamental tone taken as basis.

Owing to the general application of the decimal system, a decimal subdivision is favoured in physical work, and pitch intervals of centi-octaves and milli-octaves are used; these are also shown in Table I.

The octavo provides a method for ascribing numerical values to differences in pitch. To be able to deduce the absolute pitch from the frequency, the frequency of a specific tone must be fixed as a basis. Various conventions have been adopted for this purpose. The standard of pitch of orchestral instruments is based on "A" whose frequency according to the socalled international scale is 435 cycles, while the socalled physical scale takes 430.5 cycles for this tone, for it is considered an advantage that C^3 then has a frequency of 1024, i.e. exactly 10 octaves above 1 cycle. In American scientific literature a fundamental tone of 1000 cycles is employed in conjunction with decimal subdivision of the octave.

Fig. 2 shows the compass of a number of common musical instruments and brings out the importance of the various frequency bands as well as the frequency of the tones in the two aforementioned scales.

Loudness and Sound Intensity

Just as the logarithm of the frequency has been employed as a measure of the pitch, the logarithm of the sound intensity [3]) is used to express the intensity of an auditory sensation. The justification for this is here however not equally valid since the auditory sensation is not a complete parallel to the logarithm of the sound intensity. The true relationship between these two magnitudes is difficult to establish, since the loudness is determined not only by the sound intensity but also largely by the frequencies composing the sound.

Furthermore, the estimation of equivalent differences in loudness is much less accurate and far more difficult than is possible with differences in pitch. The results of experiments designed to determine the relationship between loudness and sound intensity are far from satisfactory, and their discussion is beyond the scope of the present article. It is nevertheless possible to determine with a fair degree of accuracy the equality of loudness of two sounds, even if they differ considerably in character. At a given frequency and sound intensity, the difference in intensity which produces a just perceptible difference in loudness can moreover be established fairly accurately. It is found that for a tone of approximately 1000 cycles the ratio I_2/I_1 of the sound intensities between which the ear can still just differentiate is constant over a wide range and is approximately 1.2. If a logarithmic scale is used two sound intensities just at the threshold of differentiation will be roughly the same distance apart over a greater part of the graph. This is very convenient, where, for instance, it is desirable for the accuracy of a graph to conform to the acuity or sensitivity of differentiation of the ear. Moreover, with this scale the very wide compass of intensities of 1 : 10^{13} to which the ear reacts (see *fig. 3* and *4*), can be covered, which

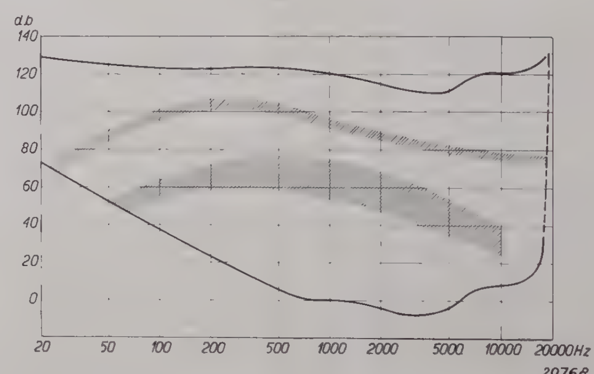

Fig. 3. Range of audibility. The minimum sound intensity just still perceptible to the ear (threshold value) and the maximum sound intensity which can be tolerated by the ear are plotted here as continuous lines as a function of the pitch. Thus within this range all tones detectible with the ear are located. The ranges are also shown hatched which cover the maximum sound intensities at various frequencies of an orchestra of 75 pieces playing forte: below these the corresponding values for speech are given. (According to J. L. Sivian, H. K. Dunn, S. D. White, Journ. acoust. Soc. Amer., **2**, 330, 1931).

would be quite impossible with a linear scale. The logarithmic scale offers other practical advantages, which will be discussed at the conclusion of this article.

Bel and Neper

To ascribe a numerical value to the difference in intensity between two sounds we can therefore adopt the convention "The logarithm of the ratio of their sound intensities shall be N", although

[3]) The sound intensity of a progressive wave is the amount of energy which is conveyed by the sound wave in unit time and per unit of surface normal to the direction of flow. The unit used to express this intensity is the erg per sec per sq. cm, although frequently the intensity is given in watts per sq. cm = 10^7 erg sec^{-1} cm^{-2}.

it is evident that this cumbersome method is useless. For this reason the units "Bel" and "Neper" have been introduced.

The difference between these two units lies in the first place in the choice of the base of logarithms used [4]), the Briggsian base of 10 being selected for the "Bel" and the base of natural logarithms e = 2.718 for the"Neper". They also differ in the type of the physical magnitudes to which they are applied: The bel is always used for expressing energies or powers, while the neper is used for amplitudes, such as sound pressure, velocity of sound (sound-particle velocity), electric currents or voltages. To exemplify the fundamental difference between these two units and to bring out their relationship, the following discussion is instructive:

The intensity of a plane progressive sound wave at a certain point is determined by the sound intensity I (see footnote 3), by the intensity of the pressure fluctuations p or by the sound-particle velocity v. These factors are related to each other as follows:

$$I = p \cdot v = \frac{p^2}{\varrho c} = \varrho\, c\, v^2, \quad \ldots\ldots (1)$$

where ϱ is the density of the medium of propagation (for air ϱ is 0.0013 gr per cm³) and c is the velocity of propagation through the medium (for air c = approximately 332 m per sec). This equation is valid only for plane progressive waves.

Similarly, in the transmission of electrical energy, either the power W transmitted, the voltage e or the current i can be stated, provided that in the latter case the resistance R of the consumer is also given, thus:

$$W = e\, i = \frac{e^2}{R} = i^2 R \quad \ldots\ldots\ldots (2)$$

It is seen that the product $\varrho\, c$ in equation (1) bears a close analogy to the resistance R in equation (2). $\varrho\, c$ is termed the "acoustic resistance". For air $\varrho\, c = 41$ gr cm^{-2} sec^{-1}. *Fig.4* gives the relationship between the ratio of the amplitudes, the number of nepers or decibels and the ratio of the intensities or energy values.

It follows from equations (1) and (2) that the logarithm of the ratio of two powers or intensities is double the logarithm of the ratio of the corresponding voltage, current, pressure, or velocity amplitudes.

$$\log \frac{W_2}{W_1} = 2 \log \frac{e_2}{e_1} = 2 \log \frac{i_2}{i_1}.$$

$$\log \frac{I_2}{I_1} = 2 \log \frac{P_2}{P_1} = 2 \log \frac{v_2}{v_1}.$$

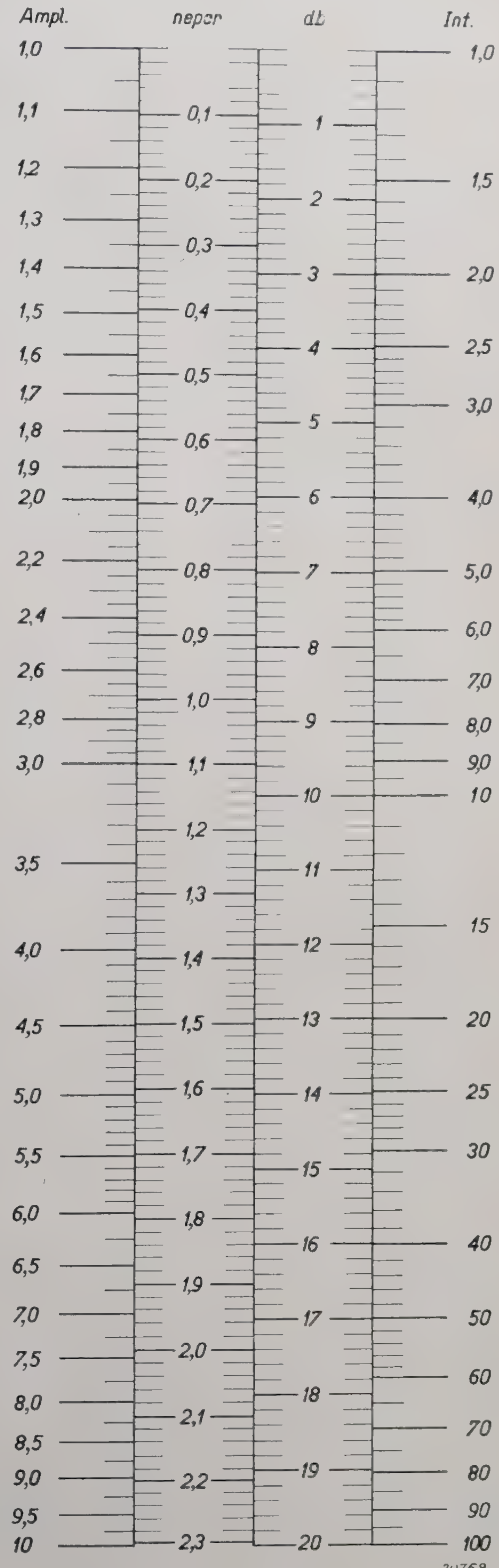

Fig. 4. Scale subdivision in amplitude ratios, nepers, decibels and intensity ratios.

[4]) We shall write $log_{10}\, a$ as $lg\, a$ and $log_e\, a$ as $ln\, a$, the simple relationships between these logarithms being:

$lg\, a = 0.434\, ln\, a$ and $ln\, a = 2.3\, lg\, a$.

In the following we shall term the logarithm of the ratio of two magnitudes a difference in level, thus arriving at the following definitions for the bel and neper:

Bel: The difference in level between two powers or intensities is N bels, when:

$$lg \frac{W_2}{W_1} = N \quad \text{or} \quad \frac{W_2}{W_1} = 10^N.$$

Decibel: The decibel is the tenth part of a bel, so that the difference in level of two powers or intensities is n decibels when:

$$10\ lg \frac{W_2}{W_1} = n \quad \text{or} \quad \frac{W_2}{W_1} = 10^{\frac{n}{10}}.$$

Neper: The difference in level between two amplitudes (of voltage, current, pressure, velocity, etc.) is M nepers when:

$$ln \frac{a_2}{a_1} = M \quad \text{or} \quad \frac{a_2}{a_1} = e^M.$$

In the light of these definitions the difference in level of two powers or intensities can only be expressed in bels or decibels, while the difference in level between two voltages or veliocities must not be expressed in bels but in nepers. To calculate the difference in level between two powers the measured voltages *(e)*, currents *(i)*, velocities *(v)* or pressures *(p)* are naturally useful, provided the resistance of the consumer is the same in both instances. The following equation can then be used:

$$n = 10\ lg \frac{W_2}{W_1} = 20\ lg \frac{e_2}{e_1}$$

If it is remembered that *log 2* = 0.30 and that 1 decibel corresponds to an energy increase of approximately 25 per cent, the intensity ratio corresponding to a specific number of decibels can readily be calculated mentally. The following series of corresponding values is then found:

Decibels	0	1	2	3	4	5	6	7	8	9	10
Ratio	1	1.26	1.6	2.0	2.5	3.2	4.0	5.0	6.3	7.9	10

To determine the ratio of the amplitudes the number is sought corresponding to half the number of decibels.

Sound Intensity Level and Loudness Level

Decibels and nepers are units for expressing differences in level. With pure tones the loudness itself can be established by taking a specific sound intensity as zero level. The difference in decibels compared with zero level is termed the sound intensity level.

Tabel II. Relationships between different acoustic magnitudes for plane progressive waves in air.

Decibels	Phons	Intensity	Sound pressure	Sound-particle velocity	Amplitude of vibrations in air at
Above 10^{-16} wattsper sq. cm	db above $2.5 \cdot 10^{-16}$ watts per sq. cm	10^{-9} watts per sq. cm	Dynes per sq. cm	in air, 10^{-3} cm per sec	1000 cycles, 10^{-6} cm
64	60	0.25	0.32	8	1.8
65	61	0.32	0.36	9	2.0
66	62	0.40	0.40	10	2.2
67	63	0.50	0.45	11	2.5
68	64	0.63	0.50	12	2.8
69	65	0.8	0.56	14	3.2
70	66	**1.0**	0.63	16	3.6
71	67	1.25	0.71	18	4.0
72	68	1.6	0.80	20	4.5
73	69	2.0	0.89	22	5.0
74	**70**	2.5	**1.0**	25	5.6
75	71	3.2	1.1	28	6.3
76	72	4.0	1.25	32	7
77	73	5.0	1.4	36	8
78	74	6.3	1.6	40	9
79	75	8	1.8	45	10
80	76	10	2.0	50	11
81	77	12.5	2.2	56	12
82	78	16	2.5	63	14
83	79	20	2.8	71	16
84	80	25	3.2	80	18

It is a matter of serious concern that not only is more than one zero level used but that moreover reference is frequently omitted to the actual zero level used as a basis of comparison [6]). In America

[5]) The following equivalents are employed for converting nepers into decibels, provided that the resistances are equivalent:
1 decibel = 0.115 neper; 1 neper = 8.7 decibels.
But it is incorrect to calculate the amplification of an amplifier with an input impedance of R_1 = 1 megohm and a resistance load of R_2 = 1000 ohms, in terms of decibels as $n = 20\ lg\ e_2/e_1$. The amplification is moreover given by the expression:

$$n = 10\ lg\left(\frac{e_2^2}{R_2} \cdot \frac{R_1}{e_1^2}\right) = 20\ lg \frac{e_2}{e_1} + 10\ lg \frac{R_1}{R_2} = 20\ lg \frac{e_2}{e_1} + 30.$$

[6]) The whole statement of data may as a result become meaningless. "The intensity of a loudspeaker is 80 decibels" has no meaning, unless it is stated which intensity is taken as zero level and at what distance this intensity is measured, or, if the total power output is meant, which power value has been selected as zero level. The sentence above can therefore mean: "The sound intensity in the axis of the loudspeaker at a distance of 2 m is 80 decibels above 10^{-16} watts per sq. cm", or also e.g.: "The total output of the loudspeaker is 80 decibels above 1 microwatt."

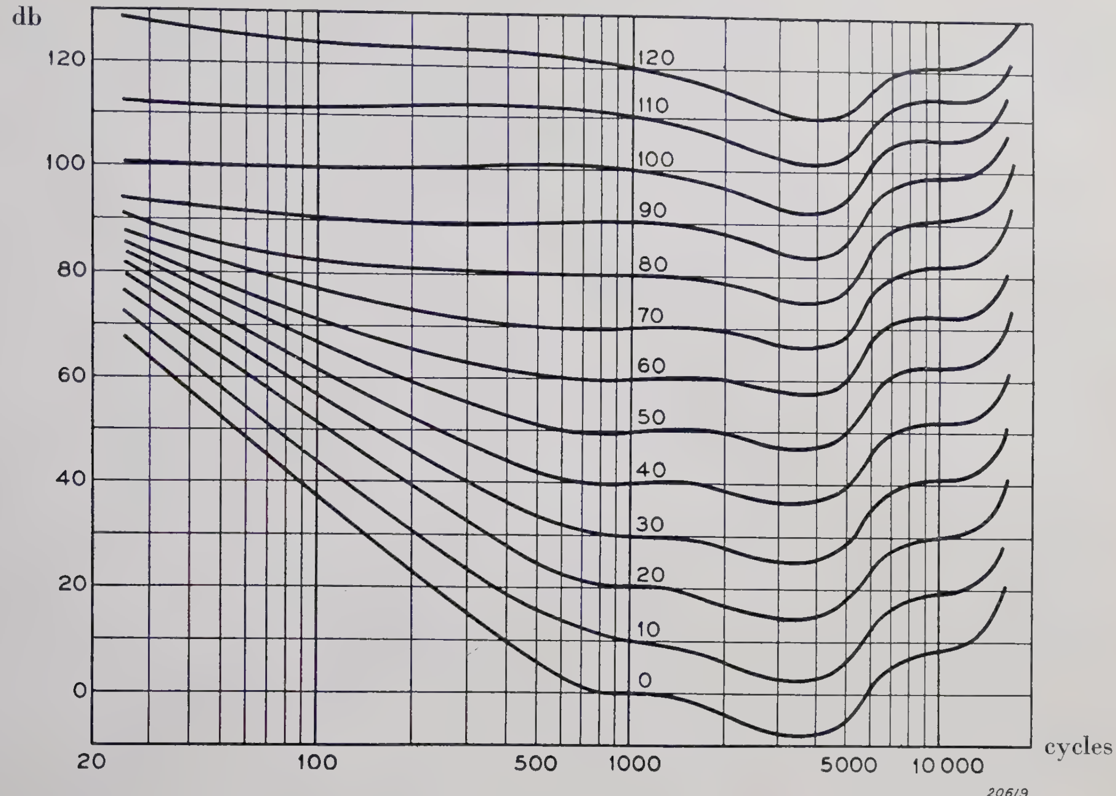

Fig. 5. Sound intensity level in decibels above 10^{-16} watts per sq.cm as a function of the frequency for constant loudness. The numbers next to the lines indicate the loudness level, i.e. the sound intensity level of the corresponding loudness for a 1000-cycle tone. The bottom line represents the threshold of audibility of the human ear. It is striking that the corresponding sound intensity increases considerably with diminishing frequency, while the curves for higher loudness values are much flatter.
The irregularity which occurs in all curves in the band between 2000 and 6000 cycles is probably due to the diffraction of the sound waves around the head. In measurements of the sound pressure in the ear canals the curves are smooth. (According to H. Fletcher and W. A. Munson, Journ. acoust. Soc. Amer., **5**, 82, 1933).

an intensity of 10^{-16} watts per sq.cm which lies approximately at the threshold of audibility of the ear is used as zero level; in Germany the standard intensity level corresponding to 1 dyne per sq.cm sound pressure in a plane wave is put equal to 70 decibels. Zero level then has a pressure of $0.32 \cdot 10^{-3}$ dyne per sq. cm and a sound intensity of $2.5 \cdot 10^{-16}$ watts per sq. cm. In general the use of the decibel is limited to differences in level only and the level itself is expressed in phons, 70 phons corresponding to a sound pressure of 1 dyne per sq. cm. In *Table II*, the comparison is given for a plane progressive wave between the intensity level (decibels above 10^{-16} watts per sq. cm and phons) and the intensity, as well as the corresponding effective value of the pressure fluctuations and the sound-particle velocity. As a guide the amplitudes of the air particles are given in the last column for a frequency of 1000 cycles [7]).

For sounds differing in character the loudness may differ considerably at the same intensity level. In particular pure tones with different frequencies and at the same level exhibit very marked differences in loudness. In *fig. 5* the intensity level at constant loudness is plotted as a function of the frequency. It is seen that a much higher sound intensity corresponds to an equivalent loudness at low frequencies than at medium frequencies. The difference may be as great as 60 decibels, i.e. by a factor of 1 million.

The sound intensity which is just at the limit of audibility is termed the threshold value. The line of constant loudness corresponding to this value is marked with the numeral 0 in the figure. The other lines are marked with the sound intensity level which is required to obtain the loudness in question at 1000 cycles. This numerical value is termed the loudness level. Also for compound sounds, such as street noises, the loudness level can be determined by comparison with a tone of 1000 cycles. A selection of loudness levels of various common sounds and noises is reproduced in *fig. 6*.

[7]) The amplitude a is calculated from the effective value of the sound-particle velocity for a specific frequency f using the expression:

$$a = \frac{v}{2\pi f}\sqrt{2}.$$

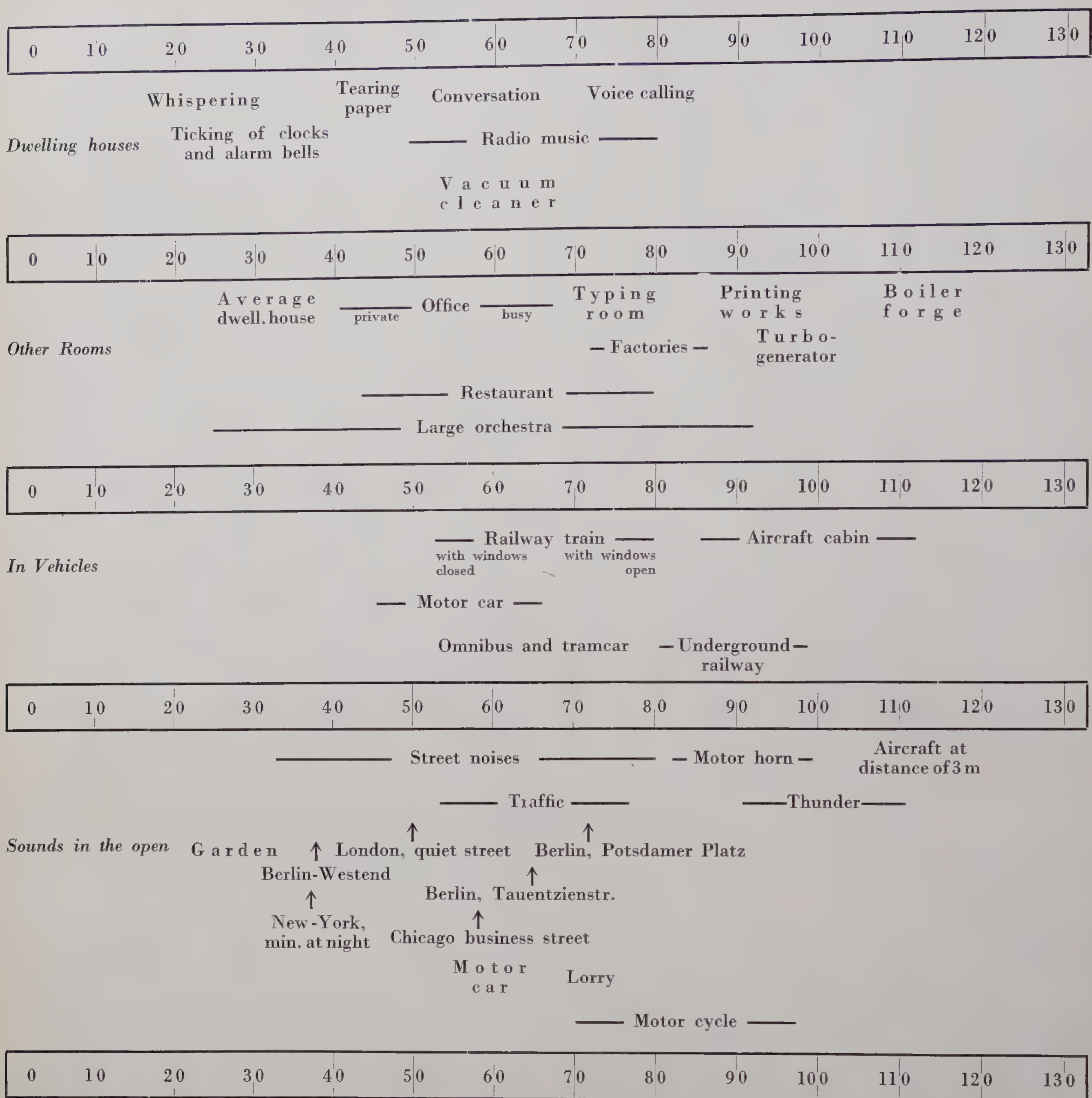

Fig. 6. Range of loudness level in phons for various common sounds and noises.

Comparison of Diagrams with Logarithmic and Linear Scales

To illustrate clearly the differences between the linear and logarithmic scales used for graphical representation, the same arbitrary characteristic showing, e.g. the variation of sound intensity of a loudspeaker, has been plotted in various ways in *fig. 7* as a function of the frequency.

1) The first point which becomes apparent, for instance, on a comparison of *a* and *b*, is that with the logarithmic frequency scale all octaves are shown to an equal extent, while with the linear scale the band below 1000 cycles, which is the most important as regards audibility, has been compressed to an insignificant width. On the other hand the band above 5000 cycles, which has a compass of only $1^1/_2$ octaves, takes up a disproportionately large part of the figure.

2) Secondly (cf. *a* and *b*) the widths of the various peaks and troughs of the curves are equal on the logarithmic scale where they are the same percentage fractions of the frequency. This gives a better insight into the damping of the resonant frequencies, which in certain

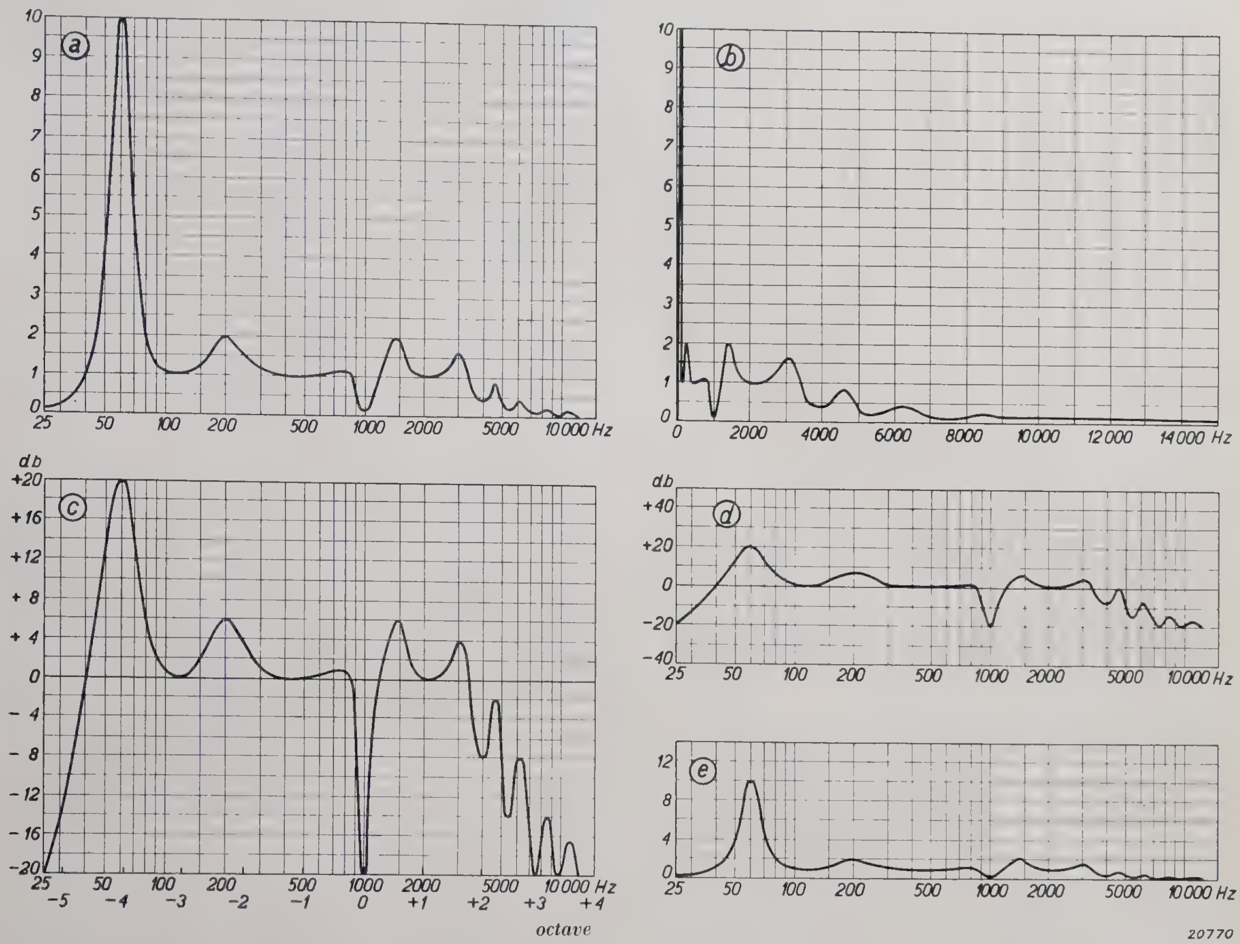

Fig. 7. Representation of one and the same frequency characteristic on linear and logarithmic scales along the abscissa and ordinate.
a abscissa with logarithmic scale, ordinate with linear scale;
b abscissa and ordinate both with linear scales;
c abscissa and ordinate both with logarithmic scales.
d as for *c* but with reduced scale along the ordinate.
e as for *a*, but with reduced scale along the ordinate.

circumstances are responsible for abnormalities.

3) Thirdly (cf. *a* and *c*) it is evident that the linear intensity scale brings out more clearly the peak at 60 cycles than the trough at 1000 cycles, while these are of the same size on the logarithmic scale.

4) The character of the curve above 5000 cycles (cf. *b* and *c*) is almost flat with the purely linear scale, but on the logarithmic scale still reveals marked irregularities which certainly affect the quality of sound reproduction.

5) It is interesting to note that on measurements with e.g. a quarter of the power the shape of the curve is not changed at all if a logarithmic scale is used. The only difference is a displacement of the whole curve downward by 6 decibels. When using a linear intensity scale (cf. *a* and *e*) the curve is however considerably distorted and in case *e* appears to be much smoother.

6) The objection is frequently advanced against a logarithmic scale that the irregularities of a characteristic are smoothed out. In general this is not the case, for although the peaks are reduced in size as compared with the troughs (cf. *a* and *c*) or regarded from the acoustical aspect they are reduced to their true proportions, the magnitude of the deviations yet depends entirely on the choice of unit for the scale (cf. *c* with *e*, where the logarithmic scale brings out greater irregularities, and *a* with *d* where this is the case with the linear scale).

7) The frequency and intensity range which can be conveniently covered in a single diagram is practically unlimited when using a logarithmic scale and with a linear scale is limited to a ratio of 1 : 10.

8) A disadvantage of the logarithmic scale for many applications is that the zero is located at $-\infty$ and also that negative values cannot be plotted. But since the ear itself has a specific

threshold value no objection can be raised to this from acoustical considerations.

9) With a linear scale the numerical value of the intensity of a compound sound is equal to the sum of the numerical values of its components. With a logarithmic scale this is not the case, although on this scale the total amplification or damping (attenuation) can be found directly by expressing the corresponding components in decibels and adding them. In many instances the ability to do this is alone sufficiently important to justify the use of decibels or nepers.

THE PLAYING SPEED OF GRAMOPHONE RECORDS

By J. DE BOER.

If a gramophone record is not played at the correct speed[1]), both the pitch and time of the music will be reproduced incorrectly. At Philips Laboratory a series of experiments have been carried out with the object of establishing the reaction of listeners to this effect. A disc of Beethoven's Fifth Symphony was played at different speeds and each member of the audience of about 30 persons was then asked whether the speed was correct, too fast, or too slow. The results of these tests are shown graphically in *fig. 1*, where the percentage of the listeners who judged that the record had been played at the right speed is given for different playing speeds.

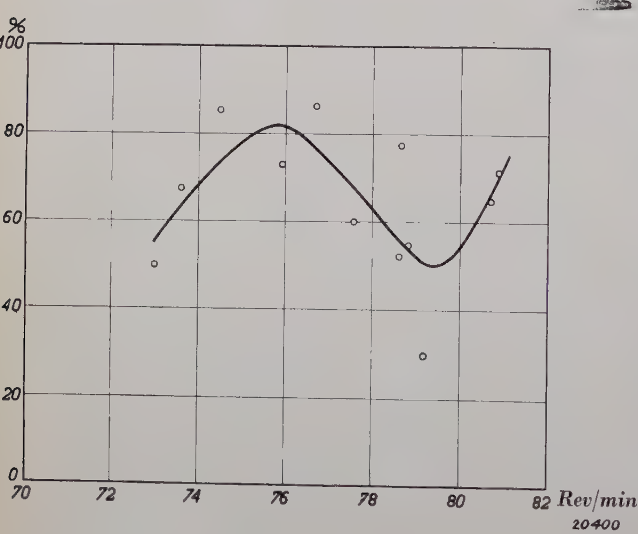

Fig. 1. Percentage of listeners who judge reproduction to be good at different playing speeds.

Owing to the small number of listeners entailed the accuracy of the points plotted is somewhat uncertain, although the shape of the curve was later confirmed in a second series of tests. It may be deduced from this curve that the correct playing speed for this record is 76 revolutions per minute, instead of 78 revs. per min. as printed on the record.

This divergence was confirmed by an observer with a perfect ear. According to this observer also, the pitch (C minor) of the music reproduced was correct when the playing speed was 76 rev. per minute. In addition, the frequencies of two tones on the record, e′ and g″, were also determined objectively. With an equal tempered scale with a′ = 435 cycles, these frequencies should be 308 and 775 cycles respectively. These tones were recorded on a strip of film by the Philips-Miller system of sound recording. The film strip was passed through the reproducing machine in the form of an endless band, so that the pitch could be readily compared by the beat method with a calibrated tone generator. The frequencies were found to have the specified values when the playing speed of the records was 76 ($\pm$ 0.3) revolutions per min. This value is in agreement with the results obtained in the tests with an audience and with those made by an observer with a perfect ear.

The difference between the optimum playing speed and the specified speed is probably not due to the speed of the recording apparatus, making the discs, being incorrect. It is more feasible that the observers took as a basis an equal tempered scale with a′ = 435 cycles, while the orchestral instruments were tuned to a higher pitch.

The result of this investigation demonstrates that the public is able to distinguish whether the pitch and time of the music reproduced are correct. The curve in fig. 1 again shows an increase at a speed of approximately 80.5 revolutions per min., which may be associated with the fact that at this speed the notes are just transposed by half a tone and that the music is then reproduced at a pitch more familiar to listeners than at intermediate playing speeds.

[1]) This speed is defined as the speed at which the record was originally recorded.

A UNIVERSAL TESTING SET FOR RADIO VALVES

By D. ERINGA.

Summary. A testing set is described which combines the functions of a receiving-valve test unit and a universal measuring unit.

All switching operations are performed automatically by the closing of a contact bridge with 140 contacts initiated after inserting a selected code card into the bridge. The efficiency of a receiving valve is indicated by the deflection of the pointer into either the red or blue area of the scale of the milliammeter. Measurements of voltages, currents, resistances and capacities and the output voltage of wireless receivers can also be carried out with this apparatus. Resistances are measured on direct current and condensers with 50-cycle alternating current.

Introduction

For a long time the need has been felt for a test set for radio valves, which was easy to manipulate and with which the efficiency of radio valves in service could be tested without extensive laboratory equipment. An apparatus of this type is required where a radio dealer wishes to demonstrate to a customer the efficient or defective functioning of a particular valve being used by the latter. The test units hitherto evolved for this purpose were either too complicated for unskilled users or did not afford a satisfactory and adequate test.

The testing set designed by us offers a very practical solution of the problem, since it fulfils the following requirements:

1) It is suitable for all standard types of valves;
2) Manipulation has been made extremely simple;
3) Mistakes in adjustment cannot damage either the valves or the testing circuits;
4) Schedules giving the limits of efficiency and serviceability for different currents and voltages can be dispensed with;
5) Incorrect manipulation of the apparatus does not make the valves appear more or less efficient than they are actually.

General Design and Manipulation of the Apparatus

The general appearance of the apparatus may be gathered from *fig. 1.* It contains the following components:

1) Twelve different valve holders to take almost all standard commercial types of valve bases (European, British and American).
2) A milliammeter with a scale divided in two portions red and blue. If the pointer reads in the red scale the valve is defective, while if it gives a reading on the blue scale the valve is in good condition.
3) A neon lamp for detecting short circuits between the individual electrodes.

Fig. 1. General view of complete testing set.

4) An electric glowlamp for detecting broken filaments.
5) A switch with eight pushes for testing the electrodes for shorts and continuity; this unit is so designed that only one push can be depressed at a time, hence not more than one switching operation can be performed at a time.
6) A potentiometer for adjusting the mains voltage to the correct value.
7) Two connector plugs for a test cord permitting measurements of voltages, currents, resistances, capacities or the output voltage of a radio receiver.
8) A slot for inserting the code cards in the socalled "contact bridge". *All switching operations required for testing a specific type of valve are performed*

automatically when the corresponding code card is inserted in the contact bridge. One or more cards are provided for each type of valve.

A view of the contact bridge is shown in *fig. 2.* One half of the bridge (on the right) consists of a

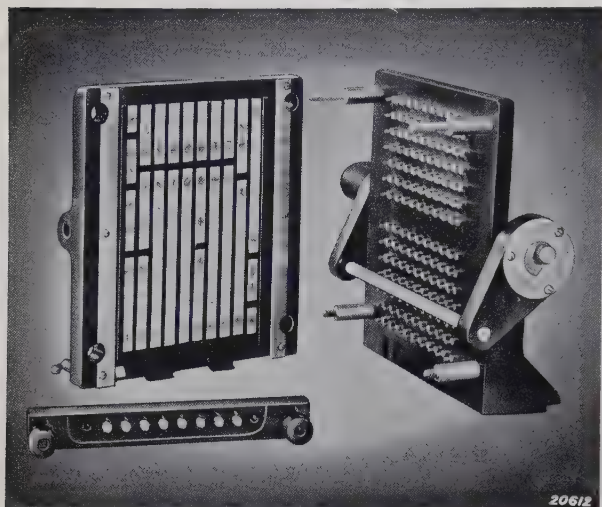

Fig. 2. View of contact bridge.

stationary plate with 140 contact pins. The other half can be displaced by means of the handle on the right hand side-wall of the apparatus and has 10 contact bars. When the code card is inserted and the bridge is closed, the contact pins in front of the perforations in the code card make contact with the bars. The card is made of an insulating material, so that where there is no perforation the contact pin is insulated from the corresponding contact bar behind the card.

Fig. 3 gives as an example the code card for the AL 4 receiving valve. At the top of the card the circuit of the valve under test is shown diagrammatically, and indicates with which connector sockets the various electrodes are connected. The distinguishing numbers of the electrodes correspond to the numbers on the valve holders and on the eight-way switch.

The connections set up when the contact bridge is closed after inserting a code card serve the following purposes:

a) Connection to the requisite filament voltage.

b) Choice of anode voltage, and if necessary adjustment of the test voltage for condensers or resistances.

c) Adjustment of the sceen grid voltage, if necessary (with rectifying valves) selection of alternating voltage applied to the anodes.

d) Adjustment of negative grid bias.

e) Fixing of correct loading resistances for measurements on rectifying valves.

f) Connecting parallel and shunt resistances to the measuring circuit, so that always the same red-blue scale can always be used for various types of valves.

g) Connection to the correct valve holder. In this way each electrode of the valve holder receives the correct voltage through the perforations in the card.

By employing the special circuit under g) above the use of a number of valve holders of the same type is superfluous.

A test is carried out as follows:

The valve is fixed in the holder, and the card inserted in the contact bridge. The glowlamp and the neon lamp L_6, which indicate the results of the test made, are not connected up through the contact bridge, so that for the time being the latter can remain open. The bridge is only closed after the tests with the open bridge have indicated no defect in the valve.

Fig. 3. Code card for an AL 4 receiving valve.

1) Immediately after inserting the valve, test the continuity of the filament;

2) Depress the pushes of the eight-way switch in succession to test for shorts between the electrodes.

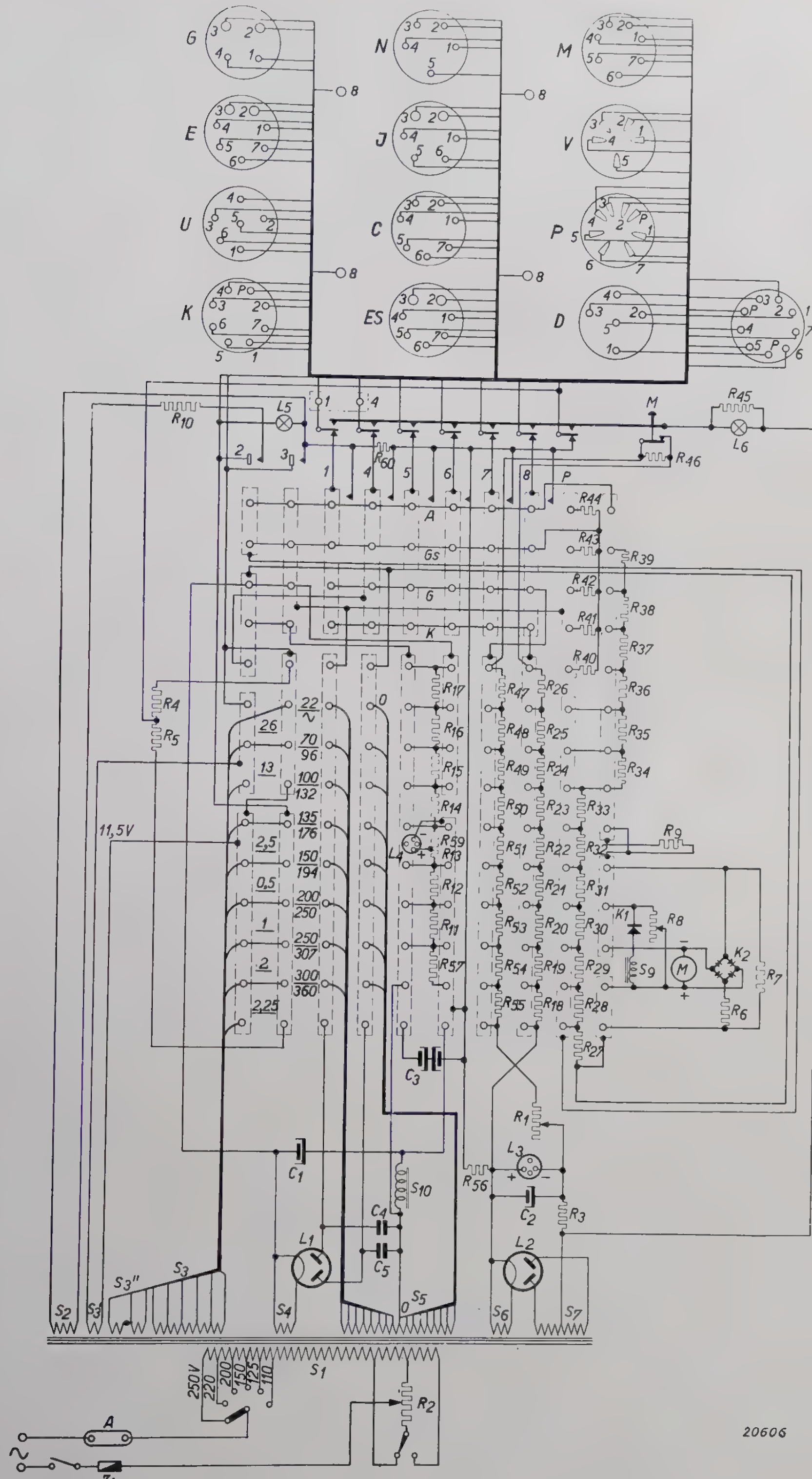

Fig. 4. Circuit diagram for testing set.

If test 1 and 2 give satisfactory results, the contact bridge is closed, and the following tests are then carried out:

3) A test for anode or auxiliary grid current;

4) A test for slope;

5) A test for electrode disconnections or possible bad insulation.

After closing the bridge, manipulation of the apparatus is again limited to pressing in succession the pushes on the eight-way switch.

Explanation of Circuits

The circuit arrangements of the testing set are shown in *fig. 4;* the principal circuits are described below. In the circuit diagram the permanent circuits are indicated by dots, while connections which are set up by means of the contact pins are indicated by a circle.

Filament voltage. The filament voltage is furnished by eight windings marked S_3, S_3', S_3'' in the circuit diagram. These windings are able to furnish all filament voltages from 1 to 56 volts in stages of $^1/_2$ volt, and partly in stages of $^1/_4$ volt. The filament voltage is taken from the first two bars on the left.

Anode Voltage. The third and fourth bars from the left serve for setting up the requisite circuits. The rectifying valve L_1 to whose anodes different alternating voltages can be applied according to requirements, furnishes the anode voltage. The anode-voltage unit has been so designed that up to about 30 mA the voltage is independent of the current tapped.

Auxiliary Grid Voltage. The auxiliary grid voltage is tapped from a potentiometer which is connected to the fifth and sixth bars from the left.

The potentiometer resistance also acts as a load resistance for the aforementioned anode voltage unit. The potentiometer is composed of the resistances R_{11} to R_{17}, The duty of the neon lamp L_4 is to maintain the auxiliary grid voltages constant at 60, 80 and 100 volts.

Loading Resistances for Rectifiers. For testing rectifying valves, resistances R_{11} to R_{17} are used as load resistances. In this case the A.C. supply from the third and fourth bars is not applied to the anodes of the rectifying valve L_1, but to the anodes of the rectifying valve under test.

Negative Grid Bias. The negative grid bias is tapped from the potentiometer in the usual way, the latter being fed from a separate rectifying valve L_2. The seventh and eighth bars from the left are provided for selecting the correct tappings.

To measure the slope of the characteristic, the potentiometer resistance can be adjusted so that that the negative grid bias is increased by 2 volts on pressing the push M. Thus from the difference in the reading on the milliammeter the difference in anode current for a change of 2 volts in grid voltage can be measured, this measurement being sufficient for most purposes.

Milliammeter with Different Shunts. The two last bars serve for connecting up a number of shunts in parallel with the milliammeter. The combinations possible with the different contacts are so numerous (about 70) that the testing ranges "bad" and "good" as marked on the meter scale of the testing set can be retained for all valves and measurements.

Protecting of Testing Set

Since the testing set is intended for the use of unskilled operators, it is naturally possible that a valve may be tested which already has a short-circuit, for instance between the grid and the cathode, or that during test a short of this type develops in the valve. It becomes imperative, therefore, to protect the milliammeter from damage. Since the method adopted by us is not generally employed, it will be described in detail below.

The circuit employed is shown in *fig. 5.* A metal

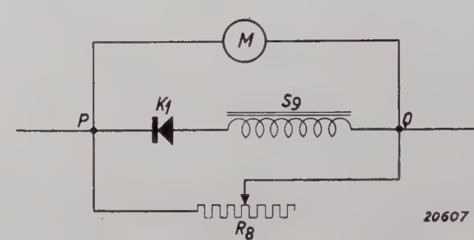

Fig. 5. Circuit diagram for instrument with oxide cell.

rectifier K_1 is connected in parallel with the ammeter as well as a correction resistance R_8. A "blocking layer" rectifier — (cuprous oxide —) cell has the property that its internal resistance depends on the voltage across its terminals. *Fig. 6* shows

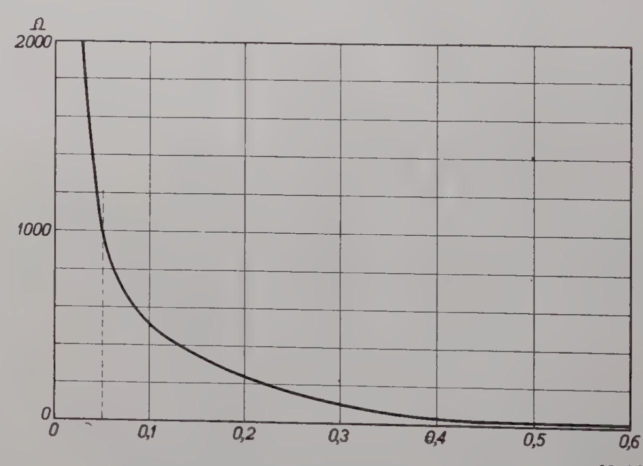

Fig. 6. Characteristics of "blocking-layer" cell.

the resistance in ohms plotted as a function of the applied voltage in volts. If the voltage between P and Q is only of the order of 0.05 volt, the resistance of the cell is about 1000 ohms, and the bulk of the current applied externally flows through the measuring instrument whose resistance is

200 ohms. If, however, the applied current rises considerably the voltage across P and Q does not increase in the same ratio, since as the terminal voltage at the cell increases its resistance diminishes considerably. If the terminal voltage is 0.5 volt, the resistance is only a few ohms. A higher current applied to the terminal P thus does not overload the instrument, for the greater part of the current flows through the cell shunt, whose resistance then has a reduced value.

This solution of the problem introduces, however, a very undesirable secondary factor. The milliammeter is not exclusively used for testing receiving valves, but is also employed for measurements on rectifying valves in which the measuringcurrent is a rectified alternating current, i.e. a pulsating direct current.

As a rule the circuits of rectifying valves are so arranged that the anode current exists only a small part of the cycle. The pulsating direct current is then approximately of the type shown in *fig.* 7. In this diagram the broken line represents

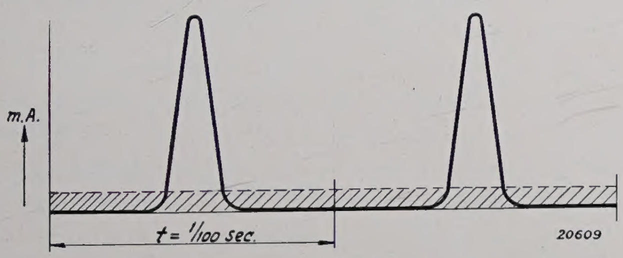

Fig. 7. Current curve for rectifying valves. The broken line represents the mean value indicated by a moving-coil ammeter.

the mean value as indicated by a moving-coil ammeter. The instantaneous value of the current during part of a period is, however, about 10 times greater, and during this interval the voltage also rises between the points P and Q. It follows from the characteristic of the cell under discussion that these peak currents will select the path through the cell instead of through the coil of the measuring instrument with its comparatively greater self-induction. Unless suitable precautions are taken the reading obtained on the instrument when testing rectifying valves will be inaccurate. To eliminate this source of error a small choke of several henries (S_9 in fig. 5) is connected behind the cell K_1. This gives the circuit K_1-S_9 so great a reactance that the resultant error is not too high. It is unfortunate that the coil S_9 is necessary since it has a certain non-reactive resistance, of about 20 ohms. This consequently reduces to some effect the shunting effect of the cell.

Testing a Receiving Valve

A simplified circuit reproduced in *fig. 8* illustrates how any receiving valve, e.g. one with three

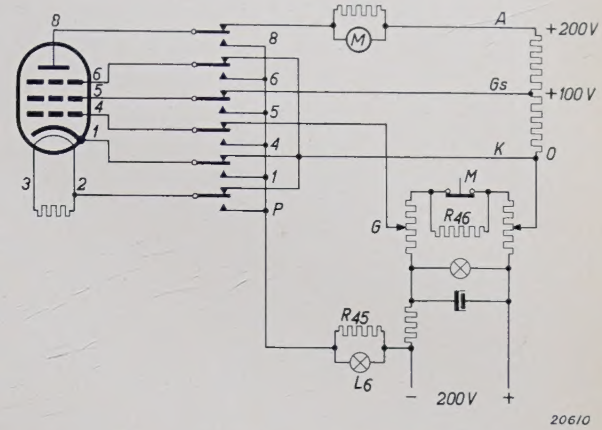

Fig. 8. Circuit for testing a pentode.

grids, has the various voltages supplied to it on closing the bridge. The feed circuit of each electrode passes through a single-pole change-over switch. The seven single-pole switches are the seven pushes of the eight-way switch shown in *fig. 9*. The tests made by means of these switches are together with the slope and anode currents of the greatest importance.

If a push is not depressed the corresponding electrode is connected to its current supply. On depressing the push, the feed circuit of the electrode is opened and the electrode is connected to the communal bar situated under the pushes, this bar having a negative voltage of approximately 200 volts. In series with the communal bar is the neon lamp L_6 with the resistance R_{45} as shunt.

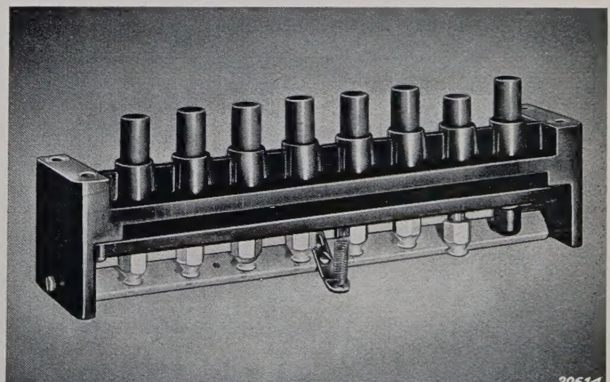

Fig. 9. Eight-way push-button switch.

When no pushes are depressed, the requisite voltages are applied to all of the electrodes and the measuring instrument M is in the anode or auxiliary grid circuit so that the current to either of these

electrodes may be tested. What happens when the various pushes are depressed?

Assume that, according to fig. 8, the filament is connected to the contacts *2* and *3*, the cathode to contact *1*, the control grid to contact *4*, the screen grid to contact *5*, the suppressor grid to *6* and the anode to *8*, and that all pushes are out of circuit. With a good valve the instrument M will then give a certain reading. If the pointer lies over the blue part of the scale the anode current of the valve is sufficient. The anode current is then above the specified limit and which is the end of the red measuring range. If now the push marked M is depressed the resistance R_{46} in the potentiometer is added to the negative grid bias circuit, and the bias is increased by 2 volts. The reading of the milliammeter will then be a few divisions lower, and the half number of these divisions for a specific valve and with a specific code card will be a measure of the slope of that valve at the testing or working point.

If push *1* is pressed, the cathode feed circuit is opened and the cathode connected through the neon lamp L_6 to 200 volts negative with respect to the common neutral point of the whole circuit. With a hot cathode the neon lamp L_6 will burn with its maximum brightness. This test is very important since by its means it can be established whether or not the cathode is emitting, also when a disconnection in the anode circuit causes no anode current reading to be obtained. On pressing push *4* (push *1* will then automatically spring back into the off position), a negative voltage of 200 volts is applied to the control grid *4*. If during heating of the valve a short has developed between this grid and the cathode, the neon lamp will burn brightly. If however the grid insulation is good and the grid connexion is not broken, the pointer of the measuring instrument will return to zero. On the other hand, if the grid lead is broken in the interior of the valve, there would be no change in the meter-reading on pressing the push. The break in the circuit may therefore be directly established. Since in this operation the neon lamp L_6 does not light and is therefore non conducting, metallic contact between the grid and the 200 volts terminal has been made for by connecting the resistance R_{45} in parallel with the lamp. Similar contact is made when pressing pushes *5* and *6*. When push *8* is pressed the meter drops back to zero, since the circuit containing the instrument is opened, while the anode is connected to the 200 volts terminal and a test thus made for insulation.

Finally, if, push P is pressed, then with certain types of valves, according to the arrangement of the perforations in the corresponding code card, the cathode heater insulation may be tested on 200 V with L_6 in circuit. If the insulation is inadequate lamp L_6 will light.

Detection of Broken Filament

The lamp L_5 is in parallel (cf. fig. 4) with the filament pins *2* and *3* and is fed from winding S_2 of the transformer through the resistance R_{10}. The voltage drop in R_{10} is of such magnitude that the voltage across lamp L_5 is just correct. On inserting a valve in the holder the filament is connected in parallel with lamp L_5, as a result of which the voltage drop across R_{10} increases to such an extent that the brightness of the lamp is considerably reduced. Immediately on inserting the valve to be tested the lamp L_5 will indicate whether or not the filament is broken.

Universal Measuring Apparatus

It is evident that an apparatus as comprehensive as that described above can also be made to carry out other measurements in addition to valve testing. In designing the apparatus this possibility was given due consideration. Leads for connecting up with current sources which it is desirable to measure can be inserted in the pushes *1* and *4* (fig. 4). To enable alternating currents also to be measured with the instrument incorporated in the test set, provision has been made for connecting a rectifying bridge K_2 in series.

By inserting suitable code cards the testing set can also be employed for the following:

a) Voltage measurements: Alternating current and direct current up to a maximum of 500 volts.

b) Current measurements: Alternating current and direct current up to a maximum of 1 A.

c) Measurements of output voltages of radio receivers.

d) Resistance measurements from 1 ohm to 5 megohms.

e) Capacity measurements from 1000 $\mu\mu$F to 200 μF.

Fig. 10 illustrates a code card for resistance measurements in the range from 1000 to 100 000 ohms.

The apparatus can also detect short-circuits. If the contact bridge is opened and one of the pushes *1* or *4* is pressed, a short in a circuit connected to the terminals *1* and *4* will be indicated by the neon lamp L_6 (see fig. 8). This is a very sensitive

method, for the rapid discovery of shorts in a receiver. It is not necessary to use a special code card for this purpose.

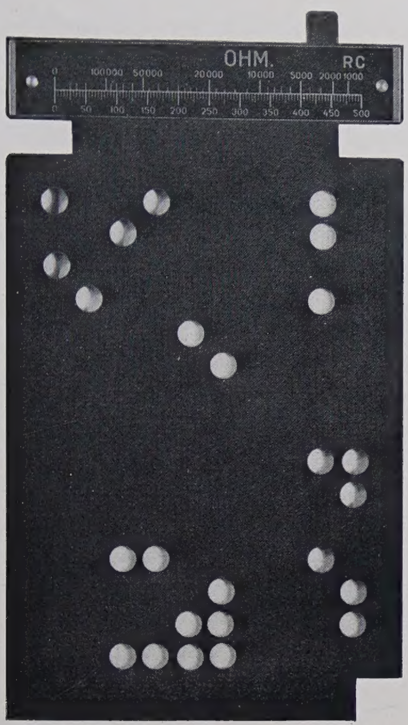

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Fig. 10. Code card for resistance measurements from 1000 to 100 000 ohms.

Constructional Details

Contact pins. One of the principal factors in ensuring the efficient operation of the testing set described here is naturally the design of the 140 contact pins. A cross-section through a contact pin is shown in *fig. 11*. The point of the pin is made of silvered brass. If when being inserted exactly vertically, the point comes in contact with one of the flat bars below it, it is quite possible that good contact will not be made should the contact surface and the pin be separated by a microscopically-thin layer of oxide or dirt. The greatest danger of this occurring is in the case of contacts which carry

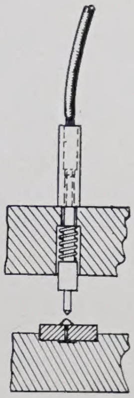

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Fig. 11. Section through one of the 140 contact pins.

no current, such as the leads to the control grid of a receiving valve. To guard against this a conical contra-contact of solid silver is mounted on the bar opposite to the conical apex of the contact pin. On closing the contact bridge these two cones slide over each other during part of the rotation, so that the contact surfaces are self-cleaning.

Contact Bridge. The contact bridge is constructed on such lines that the movable plate can be removed in a few minutes by undoing four nuts and withdrawing a spindle. The contacts are therefore readily accessible, which considerably facilitates maintenance.

Mechanical Lock. Under the contact bridge is a mechanical contact. The main transformer of the measuring instrument is only switched on after a card has been inserted in the contact bridge. This contact is so designed that the apparatus cannot be switched on if a card is inadvertently inserted incorrectly into the contact bridge.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS OF THE N.V. PHILIPS' GLOEILAMPENFABRIEKEN

No. 1128: J. L. Snoek: Messung der Koerzitivkraft an kleinen Proben (Physica, **3**, 855 - 858, August, 1936).

A method is described for the simple and rapid aproximate estimation of the coercivity on specimens of almost arbitrary shape.

No. 1129: W. Elenbaas: Die Intensitätsverteilung und die Gesamtstrahlung der Super-Hochdruck-Quecksilberentladung (Physica, **3**, 859 - 871, August, 1936).

The spectral intensity distribution is measured between 0.4 and 3 μ for several types of super-high-pressure mercury discharges. As the pressures increase the spectral lines and the continuous background broaden out, a result also obtained with increase in the current density. The total radiation was measured, a correction being made for the absorption of mercury radiation by the cooling water. Thus, e.g. the total radiation of a discharge in a tube with an internal diameter of 1 mm constitutes 75 per cent of the energy input at 1.1 amp and 800 volts per cm. In conclusion, some reasons are advanced for the fact that the ratio of the intensity of the yellow line λ (5770/5790 Å) to that of the green line (5461 Å) is here smaller than in discharges with a vapour pressure of the order of 1 atmosphere.

No. 1130: K. H. Klaassens and R. Houwink: Viskosität in Lösung und Kondensationsgeschwindigkeit von Phenolformaldehydharzen (Koll. Z., **76**, 217 - 223, August, 1936).

Viscosity measurements were made on solutions of resins with a concentration exceeding 5 per cent (socalled Staudinger limiting concentration). From the results obtained conclusions can be drawn regarding the form of the molecules. The viscosity increases with the degree of condensation at constant concentration, a behaviour which can be accounted for the transition from the small molecules in the resin into larger ones.

No. 1131: E. M. H. Lips and J. Sack: A hardness tester for microscopical objects (Nature, **138**, 328 - 329, August, 1936).

An apparatus is described by means of which the hardness of microscopical objects (such as inclusions or structural components of metal alloys) can be determined with a Vickers diamond.

No. 1132:* R. Houwink: Technisch-wetenschappelijke beschouwingen over de elasticiteit van verven en lakken (Verfkroniek, **9**, 221 - 228, August, 1936).

Report of a paper read before a meeting of the Association for Materials Technology.

No. 1133: J. L. Snoek: Kristalstructuur en magnetisme (Ingenieur, **51**, E 81 - 84, July, 1936).

A review is given of theories of ferromagnetism. Magnetic hysteresis only assumes high values when the displacement of the boundaries of the magnetic elementary regions is retarded or prevented. This state may be achieved by the artificial production of a pronounced non-homogeneous voltage distribution in the material. In modern magnetic steels an attempt is made to arrive at this result by quenching to supercool a supersaturated solid solution, after which partial precipitation is induced by heating to medium temperatures. In the case of soft materials, on the other hand, the endeavour is made to obtain a maximum homogeneity; to do this a pure material is chosen which exhibits a low magnetic-striction or in which the latter's disturbing effect has been eliminated (permalloy treatment; cooling in a magnetic field). At the same time the crystal anisotropy must also be made as low as possible.

No. 1134: J. L. Snoek: Ferromagnetische materialen (Ingenieur, **51**, E 87 - 89, July, 1936).

The subjects considered in the previous article are here discussed in greater detail with reference to various ferromagnetic materials.

No. 1135: M. J. O. Strutt and A. van der Ziel: Einfache Schaltmassnahmen zur Verbesserung der Eigenschaften von Hochfrequenz-Verstärkerröhren im Kurzwellengebiet (El. Nachr. Techn., **13**, 260 - 268, August, 1936).

The principal characteristics of receiving valves in the short-wave range are correlated. An investigation is made of the effect of introducing suitable impedances, particularly in the cathode lead, on these characteristics.

*) An adequate number of reprints for the purpose of distribution is not available of those publications marked with an asterisk. Reprints of other publications may be obtained on application to the Director of the Natuurkundig Laboratorium, N.V. Philips Gloeilampenfabrieken, Eindhoven (Holland), Kastanjelaan.